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THE ENVIRONMENTAL MEDICAL ASPECTS OF NUCLEAR BLAST

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FOREWORD

This study — describing the critical nature of selected blast-produced injuries, the development of tentative biological criteria for different levels of blast and other hazards, and the application of these criteria to nuclear explosions — stemmed from prior research in two broad areas; namely, investigations concerning the Biological Effects of Blast from Bombs carried out for the Defense Atomic Support Agency of the Department of Defense and work dealing with Selected Aspects of Weapons Effects pursued for the Civil Effects Branch of the Division of Biology and Medicine of the Atomic Energy Commission. The material was presented before the National Preparedness Symposium sponsored by the National Institute of Disaster Mobilization held November 13-15, 1962 at the International Inn in Washington, D. C.

The data, incorporating a comparative assessment of the range-yield relationship for selected "immediate" hazards due to blast phenomena as well as those due to nuclear and thermal radiation, are useful to persons — military and civilians alike — who would develop a balanced understanding of all the environmental variations which follow low- and high-yield nuclear detonations. Since the range of each major biological effect scales differently with yield and depends greatly upon the conditions of exposure, the relative quantitation of casualty potential is far from a straightforward matter. Too, because the biological criteria developed and employed were in many instances the result of extrapolations of interspecies mammalian studies, they must be used cautiously, regarded as tentative and subject to future refinement. Finally, the material presented should be viewed as a "sample" of the analytical fabric now available to help tie the source of nuclear-induced environmental variations quantitatively together with various biological responses upon which the assessment of different levels of hazard depends.

ABSTRACT

The nature of certain critical lesions seen after exposure to air blast was described and the early lethality characterizing primary and tertiary blast damage was emphasized along with the seriousness of injuries caused by blast-energized debris. Tentative criteria were developed to the end that different levels of environmental variations caused by blast phenomena could be quantitatively related to various levels of biological response. Using the "free-field" scaling laws and a mathematical model whereby translational velocities could be computed for animate and inanimate objects, the criteria were applied to nuclear explosions ranging in yield from 1 kt to 100 Mt. Thus, it was possible to specify, as a function of yield, the hazard ranges inside which various blast injuries might occur. At these ranges the associated levels of initial nuclear and thermal radiation were computed to allow at least some assessment of the relative importance of all the major hazards from nuclear detonations.

ACKNOWLEDGMENTS

Most of what is known today about blast and shock biology as it is related to nuclear explosives stems from a continuous research effort initiated at the Lovelace Foundation in 1952 under the support of the Medical Branch of the Division of Biology and Medicine of the Atomic Energy Commission. Subsequently, both laboratory and full-scale field work have been underway. The latter involved studies during the 1953, 1955 and 1957 test series at the Nevada Test Site carried out under the administrative direction of the Civil Effects Test Group, whose director arranged for collaboration with several groups to provide instrumentation and other support; namely, the Vitro Corporation of America, the Sandia Corporation, the Ballistics Research Laboratory, and the Naval Radiation Defense Laboratory. The field effort was funded by the AEC with some participation by the Federal Civil Defense Administration and the Armed Forces Special Weapons Project.

In 1959, for a year, the Defense Atomic Support Agency of the Department of Defense joined the AEC's Division of Biology and Medicine in funding the research in Blast Biology after which the DASA fully supported the effort. In addition, the Civil Effects Test Branch has provided funds for work dealing with Selected Aspects of Weapons Effects. It is with considerable gratitude that the above sources of support are acknowledged along with the interest and encouragement of the following individuals:

Dr. Shields Warren, who, when Director of the Division of Biology and Medicine, had the foresight to initiate research in Blast Biology;

Subsequent chiefs of the Division of Biology and Medicine – Dr. John C. Bugher and Dr. Charles L. Dunham – whose technical understanding helped maintain continuity of the investigative effort;

Mr. Robert L. Corsbie, until recently the AEC's Civil Effects Test Director and Chief of the Civil Effects Branch of the Division of Biology and Medicine, and his assistant and now acting chief of the Civil Effects Branch of DBM, Mr. L. Joe Deal, whose understanding and help has been unflagging;

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Mrs. Mary E. Franklin, Physics Department

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INTRODUCTION

It is a pleasure to have this opportunity to speak about the consequences of exposure to air blast which represents a potential hazard to man because of damage due directly or indirectly to:

(1) The pressure pulse that emanates radially from an explosive source;

(2) The high transient winds which accompany the pressure variations; and

(3) Events which transpire during and after the interaction of these phenomena with biological targets on the one hand and with materials comprising the immediate environment of exposure on the other. [1]

Thus, it is clear that biological blast hazards are among the immediate or early effects of a nuclear detonation. Too, if the yield is high, the damage may extend over many tens of square miles. [1] For the purpose of this discussion, the effects may be divided as follows:

(1) Primary effects are those due to variations in environmental pressure;

(2) Secondary effects are associated with the impact of debris energized by blast, shock, overpressure, wind and often gravity;

(3) Tertiary effects comprise injuries that occur as a consequence of gross bodily displacement, and

(4) Miscellaneous effects are those associated with non-line-of-site thermal phenomena due to hot gases and dust and to blast-induced fires.

Those concerned with the environmental medical aspects of nuclear blast must become interested in matters of considerable complexity. For example, Table 1 in broad terms describes six problem areas that concern those who would relate the magnitude of any given environmental variation caused by a nuclear explosion with various levels of biological response. It is necessary first to understand the uncertainties involved in "free-field" scaling; i. e., how various effects vary over reasonably flat terrain with yield, range, weapon design, burst conditions and weather. Second, the fact that any "free-field" effect may be attenuated, augmented or remain unaltered as a consequence of the conditions of exposure needs be recognized — so also must a third contingency; namely, that energy may be transferred to animate as well as inanimate objects. Fourth, biophysical interactions occur and energy is dissipated by or within biological media. These biophysical factors relate to a fifth problem area wherein biological response following exposure to various levels of single and multiple effects must be studied if realistic hazards assessment is to be forthcoming; i. e., data are needed which specify safe levels of exposure and those associated with performance decrement, injuries and different levels of lethality.

TABLE 1

PROBLEM AREAS RELEVANT TO BIOLOGIC EFFECTS OF NUCLEAR WEAPONS

Source	Design Yield Burst conditions Range Weather	"Free-field" scaling
Attenuation and Augmentation	Modification of "free-field" phenomena by geometric conditions of exposure	"Geometric" scaling
Physical Interaction	Engergy transfer to: Physical objects and biological material	Secondary events
Biophysical Interaction	Energy dissipation by or within biologic targets	Etiologic mechanisms
Biologic Response	Major medical syndromes Isolated individual effects and combined injury	Hazard assessment
Biomedical Tasks	Therapeutic and prophylactic measures	Casualty care Rehabilitation Protective procedures

Sixth and last, certain other biomedical tasks are relevant; namely, therapeutic and prophylactic measures involving casualty care, rehabilitation and the employment of feasible protective procedures.

Also, let it be clear that what is desired is knowledge about human tolerance to blast exposure. As is the case with many situations involving highly dangerous pathophysiological responses, one must rely heavily in the blast area on extrapolations and interpolations of data collected during studies of several mammalian species in the attempt to estimate quantitative environmental parameters likely to be hazardous to man. In this regard considerable data have become available over the past decade from perusal of the literature and from investigations carried out in the laboratory as well as during full-scale nuclear test operations at the Nevada Test Site.[2-34] Among the many findings applicable to nuclear blast, three groups of data are thought to be of interest to this audience. The assigned time will be used to summarize these very briefly in a selective manner; the discussion will include:

(1) The nature of the injuries which follow hazardous exposure to nuclear blast;

(2) The development of tentative biological criteria whereby the several environmental variations produced by blast may be associated with arbitrarily chosen levels of biological response; and

(3) Application of these criteria for potential hazards to nuclear weapons through use of the "free-field" scaling laws.

I. Nature of Blast-Induced Injuries

Mainly to emphasize the dangerous effects of exposure to air blast, a few of the most important lesions of a critical nature will now be summarized.

A. Primary Blast Effects

Characteristically, exposure to appropriate blast-induced variations in environmental pressure produce damage at or near the junctions of tissues of different density.[17-18, 20, 35-38] The air-containing organs are special examples of this and lung damage can lead to events that are quite critical as will be noted below.

1. Lethality-Time

Figure 1 shows the lethality-time data over 2 hrs for four mammalian species exposed to "sharp"-rising overpressures utilizing a shock tube.[27] Note that within 15 minutes, lethality was near 80 percent and ranged between 90 and 100 percent at 1 hr. For one species studied ove a 30-day, post-exposure period, about 90 percent expired in 1 day bu mortality continued up to the 17th day as noted in Figure 2.

Cumulative Percent of Mortally Wounded Animals Dying Over a Two Hour Period From Exposure to "Sharp"-Rising Overpressures of 3-4 Milliseconds Duration

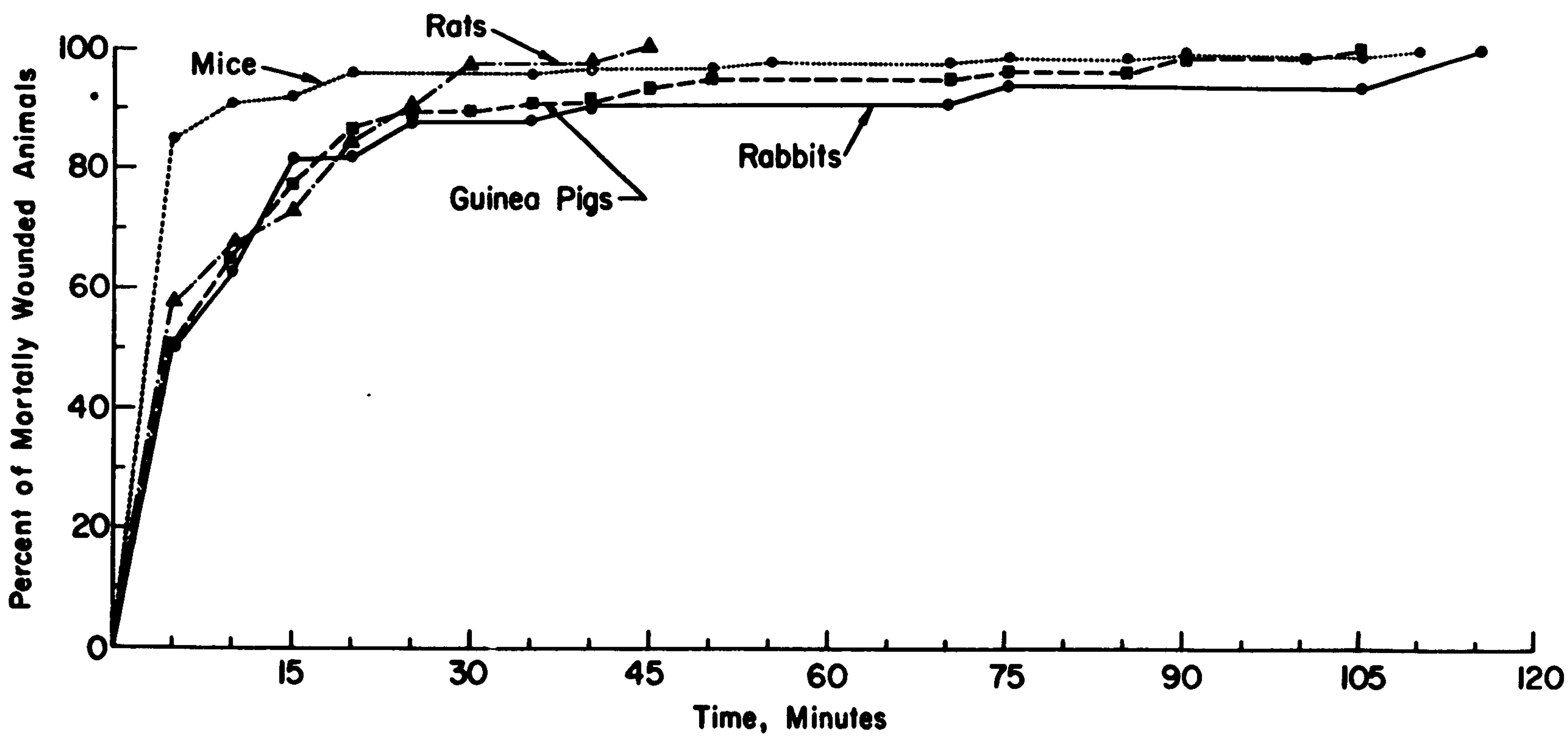

Figure 1

Guinea Pig Mortality Over a 30-day Period

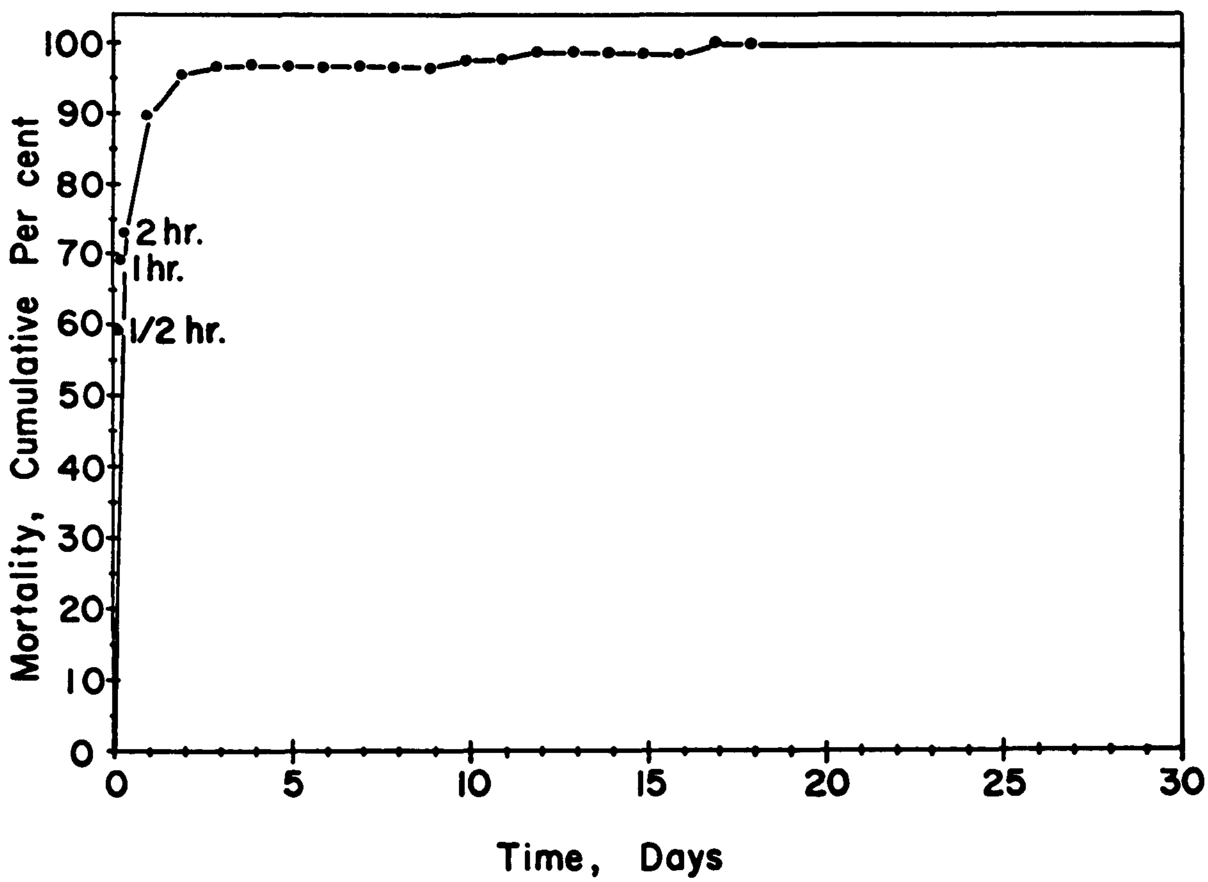

Figure 2

2. Thoracic Organs

The early lethality, typifying the primary blast effect, is associated with damage to the lung and the sequelae therefrom. Massive pulmonary hemorrhage ensues as can be seen by comparing Figure 3, a normal lung, with Figure 4, a lung from an animal that expired from exposure to nuclear blast in the entryway of an "open" shelter at the Nevada Test Site. Also, air emboli enter the pulmonary circulation; they are then carried to the heart and eventually reach various organs of the body via the arterial circulation. Figure 5 shows air emboli in the coronary vessels. A consequence is interference with the vascular supply to the myocardium and acute failure of the heart may ensue, a fact that accounts for the early demise of many cases exposed to blast overpressures.

Subsequent lethality is associated with continuing damage to the heart from small multiple air emboli and poor pulmonary gas exchange. The latter may occur because of continued hemorrhage into or edema of the lungs, a chain of events which may produce suffocation. Also, air emboli can and do embarrass the functions of critical areas of the central nervous system including the brain. Survivors of the acute challenge face the hazards of infective processes and the outcome is critically dependent upon bed rest, avoiding all exercise and the use of appropriate therapeutic measures.

It is important to emphasize two additional points. First, the primary blast lesion requires specialized therapy carried out by appropriately trained personnel. Second, the nature of the damage and the early lethality associated with serious exposures both support the common sense conclusion that exposure to hazardous overpressures should be avoided if at all possible and even at considerable cost.

B. Secondary Blast Effects

Secondary missiles may produce various types of injuries including fractures, concussion, lacerations or puncture wounds of body organs and cavities. The seriousness of the trauma is determined by a number of variables. Among them are: the mass, shape, character, and velocity of the secondary missile; the angle of impact and the area and organs of the body involved; and whether or not penetration of the skin and body wall occurs. Many of these matters have been studied extensively by those interested in war casualties and wound ballistics.[39] Certainly many wounds caused by fast-moving debris can be acutely fatal. Too, penetrations into the serous cavities of the body are almost always accompanied by serious infections, even if a nearby organ escapes critical damage. Likewise, extensive lacerations require proper care if wound suppuration is to be avoided. In addition, fractures of the long bones and other parts of the skeleton often require bed rest and expert care.

Thus, it is apparent that as far as secondary blast effects are concerned, prophylactic measures calculated to avoid infections and preventive procedures conceived to avoid or minimize exposure are matters worthy of serious consideration. A glance at Figure 6 showing multiple lacerations

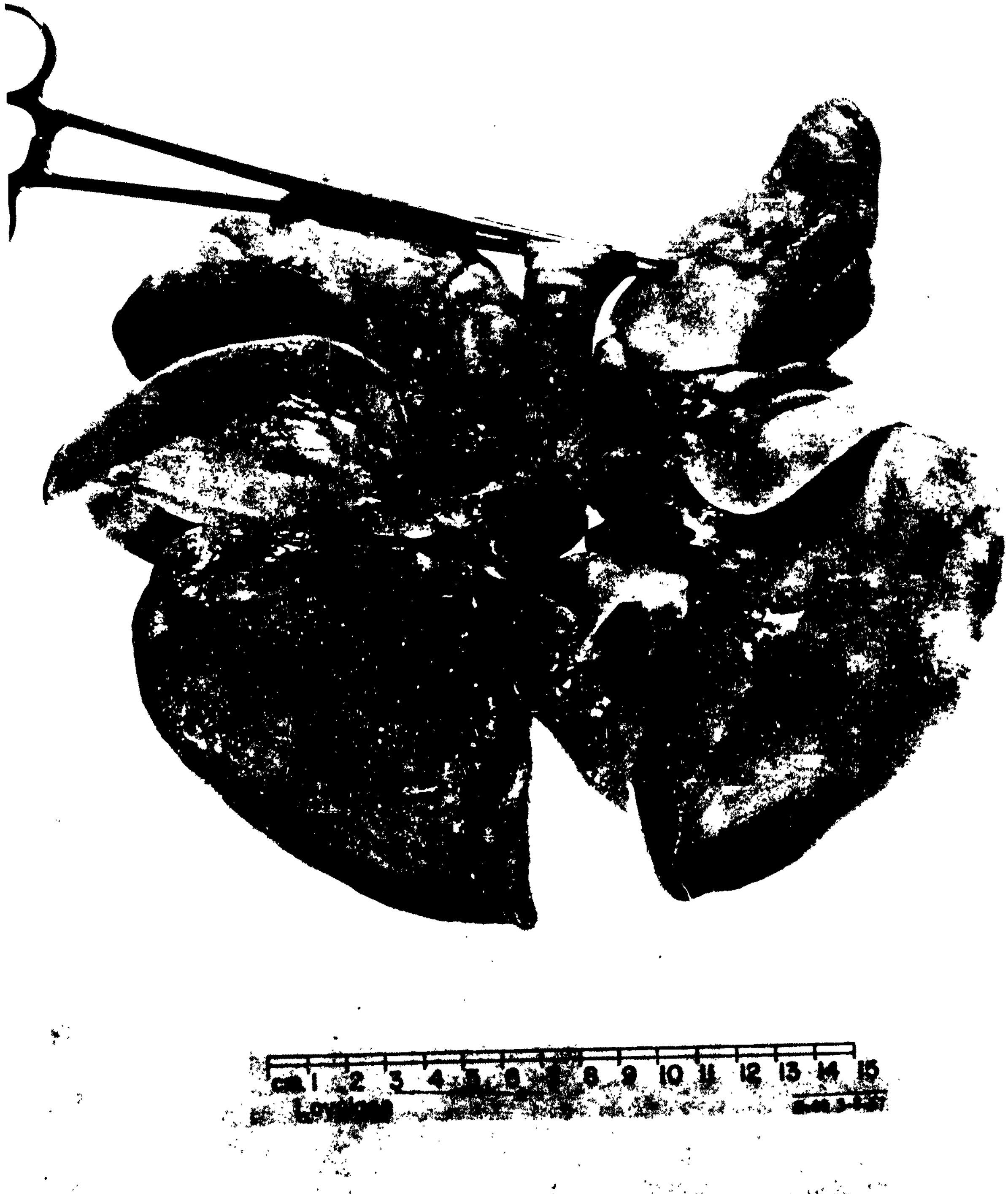

Figure 3

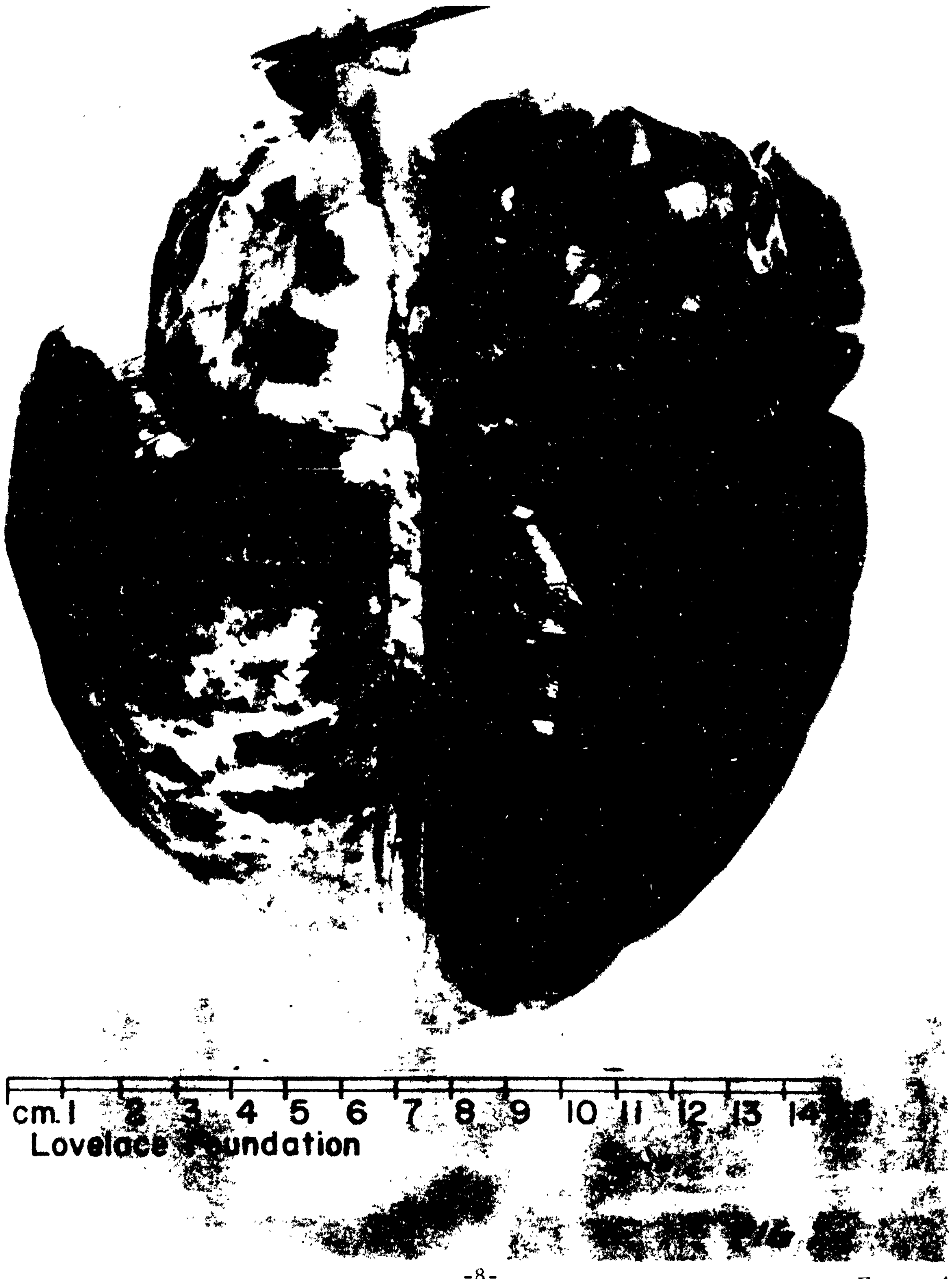

Figure 4

Figure 5

Figure 6

of the face and neck of an individual injured in the Texas City disaster[40] will, I think, emphasize the point just made.

C. Tertiary Blast Effects

Damage from gross bodily displacement may occur during the accelerative or decelerative phase of the experience. The seriousness of the injury depends, among other things, upon the magnitude of the accelerative or decelerative force, the time and distance over which these act, the velocity attained, and the area and organ of the body traumatized. In all probability, decelerative events represent the more important hazard, and, with certain exceptions, impact with a hard flat surface is likely to represent critical conditions at minimal velocities.

Lethality-Time Data

Though impact trauma has been studied over many years, few efforts have been made to investigate mammalian response under conditions wherein deceleration was almost instantaneous; i. e., only body tissues governed the stopping distance and time. Such experiements were performed several years ago and the time-lethality data obtained when impact velocities were in the range to produce lethality within 24 hrs proved to be significant. Figure 7 shows the data for 200 of 455 mammals who failed to survive longer than 24 hrs following impact with a flat concrete surface at various velocities. Note that, as with primary blast exposure, decelerative impact is a serious challenge to all species studied, there being well over 70-percent lethality within 1 hr and over 90 percent after 8 hrs.[25]

The pathophysiologic causes for the demise of the four species studied is not known with certainity, but, whichever proves to be the critical organ or body system, it is quite clear that violent impact with a hard surface is an experience to be avoided if at all possible.

II. Biological Criteria

Biological criteria for blast damage depend upon data which quantitatively relate specific levels of biological response with different levels of specified variations in the environment. The latter must be monitored as near the location of exposure as possible. Enough information now exists to establish tentative criteria for certain conditions arbitrarily chosen to represent the several blast hazards. These will now be summarized.

A. Primary Blast

Currently, it is clear that primary blast damage is largely a function of the rate, character and magnitude of the pressure rise and fall and the duration of the pulse.[6, 13, 17, 18, 27, 28, 30, 32, 34, 41, 42] For classical wave forms — those rising almost instantaneously to a maximum and decaying exponentially with time — minimal overpressures prove hazardous providing the pulse duration is beyond the critical duration.

PERCENT OF ANIMALS MORTALLY WOUNDED BY IMPACT

AS A FUNCTION OF SURVIVAL TIME

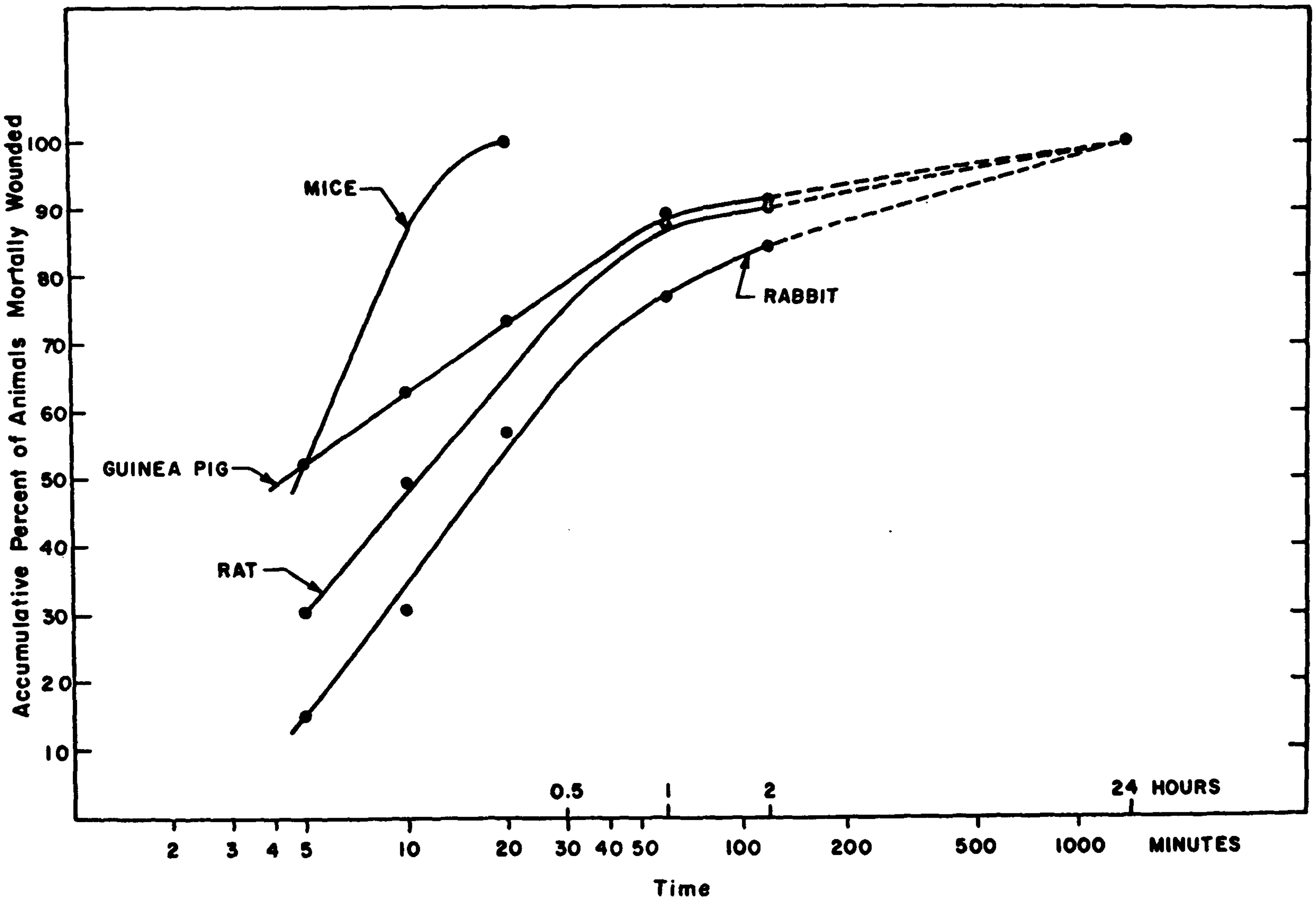

Figure 7

The latter is species dependent and represents that pulse duration shorter than which the lethal or damaging pressure rises, and longer than which, only the maximal pressure is the definitive parameter.

1. The Pressure-Duration Relationship

The above remarks are illustrated by the data in Figure 8 for six mammalian species exposed to "sharp"-rising pressures of various pulse durations.[42] The experimental points and curves represent the relationship between pulse duration and that maximal overpressure, which on the average, will produce 50-percent lethality (P_{50}). If interest is confined to nuclear yields of near 1 kt or greater, only the right side of Figure 1 is applicable. This is so because for yields as low as 1 kt the pulse duration is as long as 90 - 150 msec for overpressures as high as 100 psi.[1,31]

2. Extrapolation to the 70-kg Mammal

Using the 400-msec data shown in Figure 8, an extrapolation — given in Figure 9 — was performed to predict the P_{50} for the 70-kg mammal.[26]

3. Tentative Estimates for Man

Since one does not know whether man's tolerance to blast overpressures of long duration lies above, on, or below the regression line in Figure 9, it is currently necessary to set arbitrarily a range of pressure within which adult human tolerance is likely to be. This was recently done[42] along with procedures calculated to show the predicted lethality limits. The figures presented in Table 2 also give estimates of the overpressure likely to represent the threshold of lung injury and failure of the eardrum. The reader will note that the pressure values are set forth as maximal incident overpressures assuming a geometry of exposure that would and would not allow maximal pressure reflection; e.g., a pressure of about 6 psi can reflect to 15 psi. This fact is significant, as will be seen later, in the scaling range within which a given blast effect may occur.

It is important to note that tolerance, even among mammalian species, has not been studied in the very old or very young and that there have been no systematic interspecies studies designed to obtain a more refined estimate of the threshold for lung injury. Be this as it may, it seems reasonable to believe that man's response will not differ widely from that of other mammals. At least the figures at hand, tentative though they may be and subject to future revision as additional data become available, are currently the best that can be set forth.

4. General

Unfortunately tolerance for typical and atypical wave forms is not the same. Investigations of biologic response to smoothly rising pressures,[6,7] oscillating pressures,[6] and those rising in a stepwise manner[13],

OVERPRESSURE FOR 50 PER CENT LETHALITY AS A FUNCTION OF DURATION

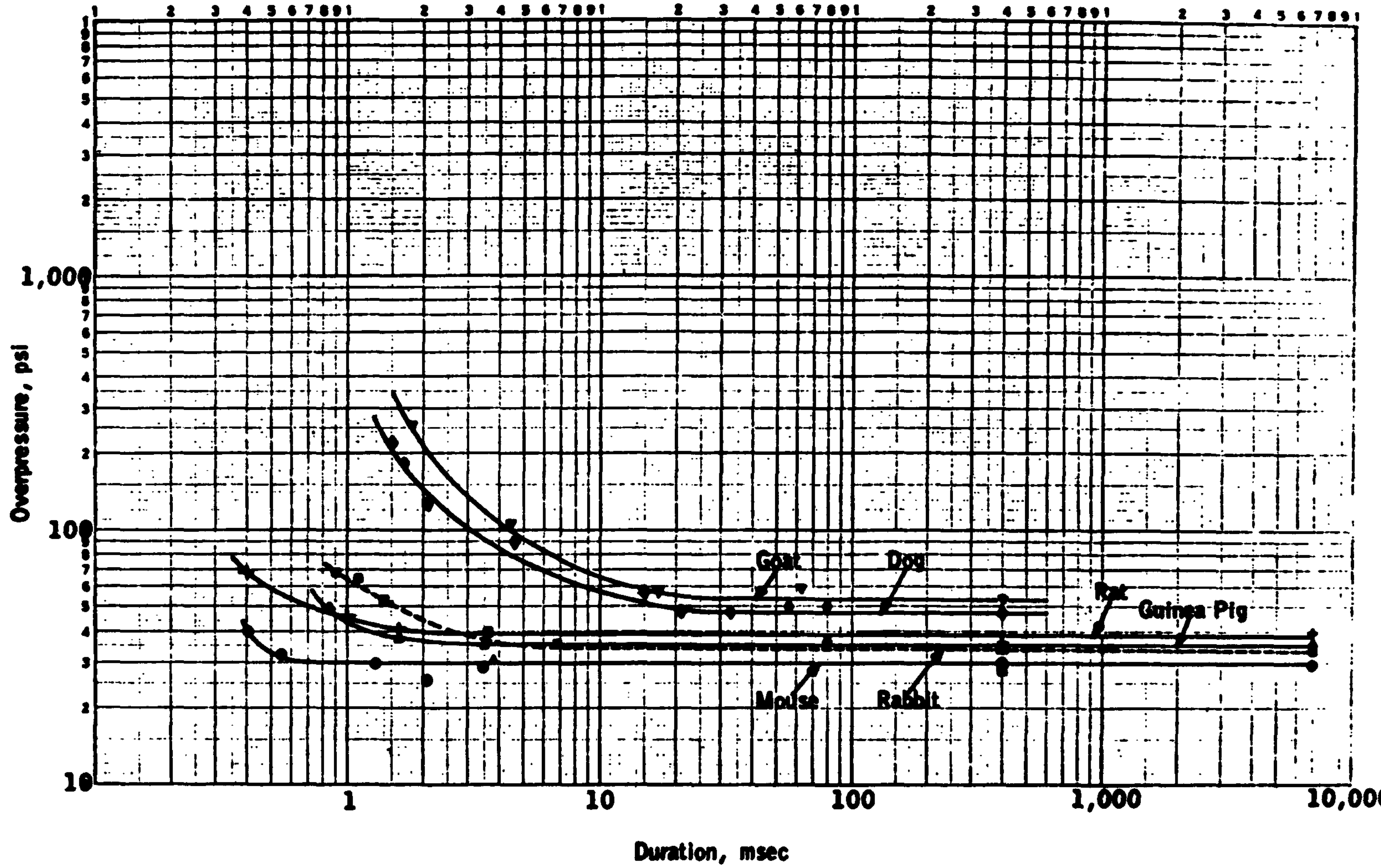

Figure 8

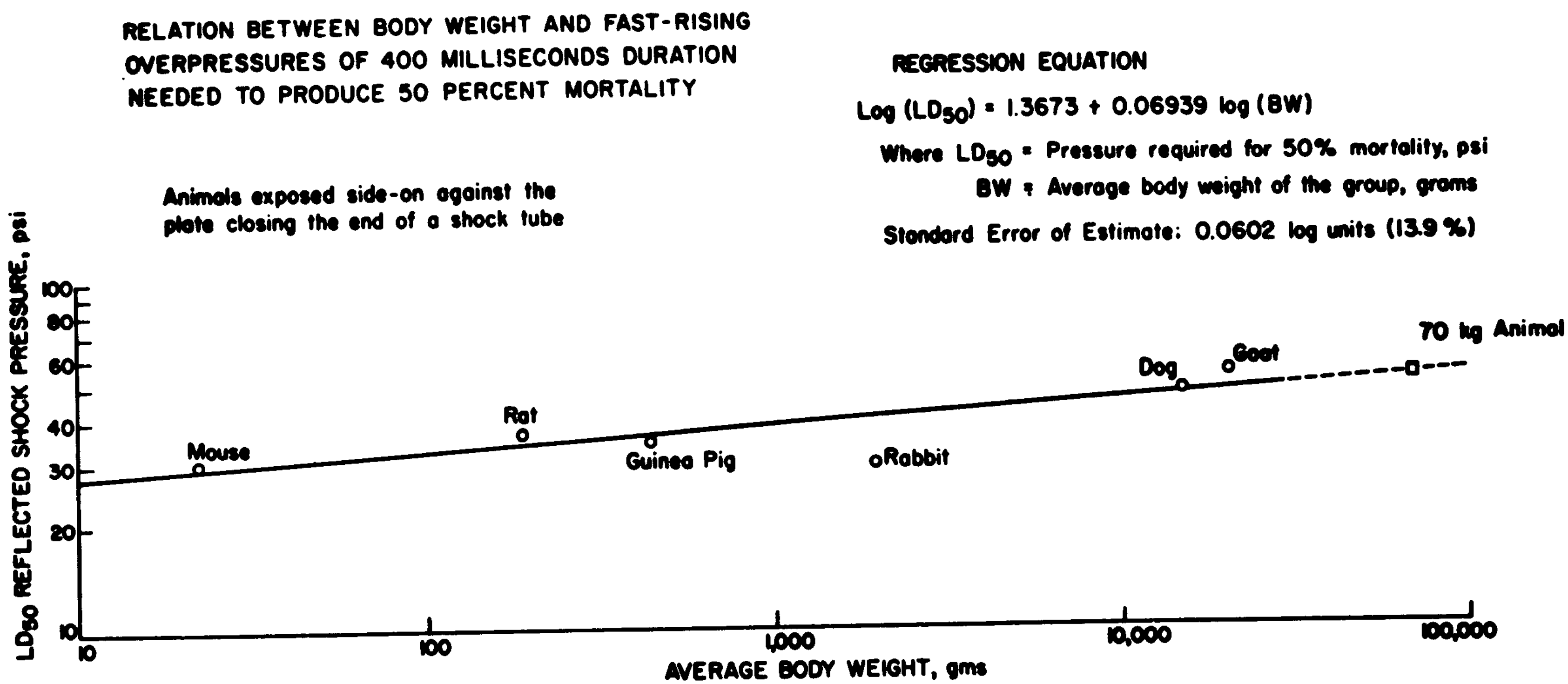
RELATION BETWEEN BODY WEIGHT AND FAST-RISING OVERPRESSURES OF 400 MILLISECONDS DURATION NEEDED TO PRODUCE 50 PERCENT MORTALITY
Animals exposed side-on against the plate closing the end of a shock tube
REGRESSION EQUATION
$\log(LD_{50}) = 1.3673 + 0.06939 \log(BW)$
Where LD_{50} = Pressure required for 50% mortality, psi
BW = Average body weight of the group, grams
Standard Error of Estimate: 0.0602 log units (13.9 %)
LD_{50} REFLECTED SHOCK PRESSURE, psi
AVERAGE BODY WEIGHT, gms
Mouse
Rat
Guinea Pig
Rabbit
Dog
Goat
70 kg Animal
10
20
30
40
60
80
100
10
100
1,000
10,000
100,000

Figure 9

TABLE 2

TENTATIVE CRITERIA FOR PRIMARY BLAST EFFECTS*

Critical organ or event	Related max pressure, psi: Incident No reflection	Incident With reflection
Lung damage:+		
Threshold	15	6.4
Lethality:+		
Threshold	30-42	12-15
50 percent	42-57	15-19
Near 100 percent	58-80	19-25
Eardrum failure:+		
Threshold	5	2.3

*Applies to "fast"-rising overpressures of "long" duration occurring at location of exposure.

+Data from WT-1179, TID-5764, WT-1467, WT-1470, DASA 1242, 1245, 1246, 1271, and Richmond, DASA Project - Unpublished.

[18,28,30,32,41] are as yet incomplete. Though the P_{50} may be increased by as much as 50 percent for smaller mammalian species, insufficient data on larger species make it imprudent to formulate any estimates for the human case.

B. Secondary Blast Effects

1. Penetrating Missiles

Some information concerning the wounding power of small glass fragments is available from earlier studies.[3] Figure 10 shows the missile-mass relationships as they determine the probability of piercing the abdominal wall of animals (about 1 cm of skin and soft tissue). Using such similar data,[3,21] it was possible to assemble the figures shown in Table 3. A 10-gm glass fragment was arbitrarily established as a "sample" criteria for penetrating missiles. As noted earlier, any penetration into a serous cavity of the body will produce a serious wound and this can occur in thin people if the velocity is in the ranges shown in the table.

It is unfortunate that similar kinds of data for sharp frangible objects are not available for the eye. However, those interested are referred to the work of Stewart[43] using steel cubes and spheres in a study of the tolerance of the rabbit eye to missile impact.

2. Nonpenetrating Missiles

Data are available in the literature[44-46] which allow tentative criteria to be established for nonpenetrating missiles assuming that the head is the critical organ. Though it may be that blows over the liver and spleen are equally hazardous, relevant quantitative figures which would establish the relative significance of head, liver or spleenic trauma apparently must await the outcome of future studies. In the meantime, Table 4 contains the best available criteria based upon the impact of a blunt object of 10 lbs, near the weight of the adult head of man.

3. Tertiary Blast Effects

a. The Impact Study

The interspecies impact study mentioned previously[25] established the V_{50} — the impact velocity with a hard flat surface associated with 50-percent lethality* for four different mammalian species. The

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*Lethality in 24 hrs was employed and the data apply to ventral impact with a flat concrete surface onto which the subjects were dropped from increasing heights.

Probability of penetration of glass fragments into the abdomen of a dog as a function of missile mass and impact velocity.

Equation: $\log v = 2.5172 - \log(\log m + 2.3054) + 0.4842\,P$

where v = impact velocity in ft/sec
m = mass of glass fragments in gms
P = probability of penetration

Standard Error of Estimate: 0.0745

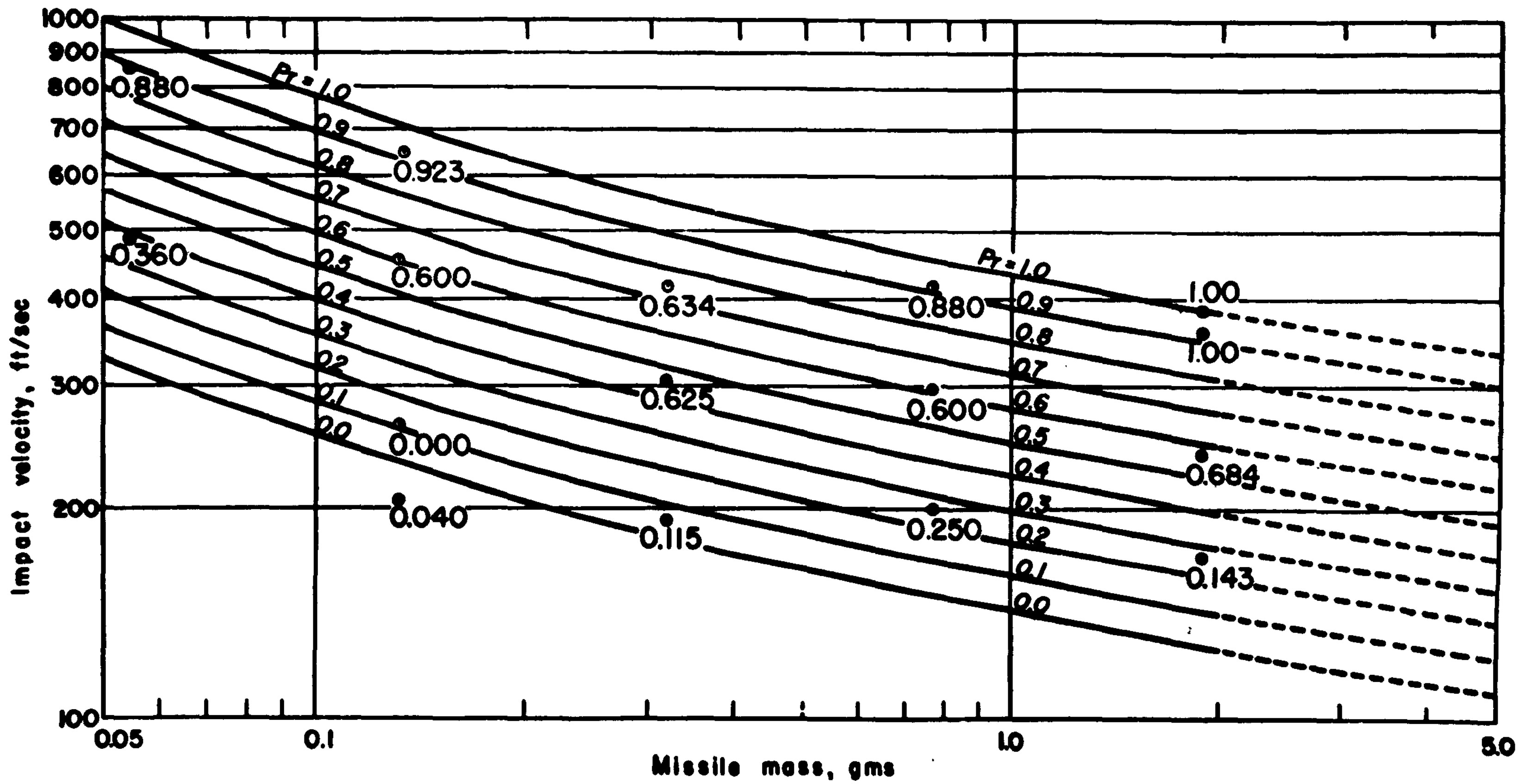

Figure 10

TABLE 3

TENTATIVE CRITERIA FOR SECONDARY BLAST EFFECTS*

Critical organ or event	Related velocity for 10-gm glass fragment ft/sec+
Skin laceration:	
Threshold	50
Serious wounds:*	
Threshold	100
50 percent	180
Near 100 percent	300

*Data from AECU-3350 and WT-1470.

+Figures represent impact velocities with unclothed biological target.

TABLE 4

TENTATIVE CRITERIA FOR SECONDARY BLAST EFFECTS

Critical organ or event	Related impact velocity for 10-lb object ft/sec
Cerebral concussion:*	
Mostly "safe"	10
Threshold	15
Skull fracture:*	
Mostly "safe"	10
Threshold	15
Near 100 percent	23

*Data from Lissner and Evans; Zuckerman and Black; Gurdjian, Webster and Lissner.

data are given in Figure 11 along with the regression curve that shows the relationship between average body weight and the V_{50} velocity. Extension of the curve to the 70-kg mammal allows one to predict a V_{50} of 26 ft/sec (18 mph). Other procedures yielded values of about 20 ft/sec (14 mph) for the V_1* velocity and 30 ft/sec (21 mph) for the V_{99} velocity.+

b. Tentative Estimates for Man

The possible application of such findings to help assess human tolerance to abrupt impact has been discussed elsewhere.[25] Included was a review of pertinent and helpful human data. Only three matters will be noted here.

First, Swearingen et al.,[47] in experiments with human volunteers, reported that impact at 10 ft/sec was tolerated by subjects both in the sitting and standing position. Second, with the possible exception of the liver and spleen, the head appears to be the human organ with the lowest tolerance to impact. Third, Gurdjian et al.,[46] using human material, determined the relationship between impact velocity and the incidence of skull fracture. Table 5 was assembled from this study. Note that the threshold for skull fracture proved to be about 13 ft/sec (9 mph), the 50-percent value close to 18 ft/sec (13 mph) and that fractures were reported in 100 percent of cases at velocities equal to or above about 23 ft/sec (16 mph).

Such data allow one to suggest tentatively that (a) 10 ft/sec is a "safe" impact velocity for the adult human, and (b) the skull-fracture data be adopted as one criteria of hazard for tertiary blast effects. It is true that this is a conservative approach and may overemphasize the hazard from impact since it assumes that the head is the only organ one should consider.

Obviously if the head escapes injury during an uncontrolled impact with an unyielding surface, other criteria are needed. For such an eventuality, it is suggested that the extrapolated figures of 20, 26 and 30 ft/sec (14, 18 and 21 mph) for 1-, 50- and 99-percent lethality obtained from the interspecies impact study be tentatively adopted. The authors are aware of the many uncertainties involved, but nothing more reliable seems to be currently at hand.

Table 6 summarizes the figures discussed above and sets forth specified biological response in relation to relevant velocities of impact with a hard flat surface. It is of interest to point out that the lethality and skull-fracture figures have an interesting parallel with a

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*The velocity associated with near 1-percent lethality.
+The velocity associated with near 100-percent lethality.

IMPACT VELOCITY ASSOCIATED WITH 50 PERCENT MORTALITY AS A FUNCTION OF AVERAGE BODY WEIGHT

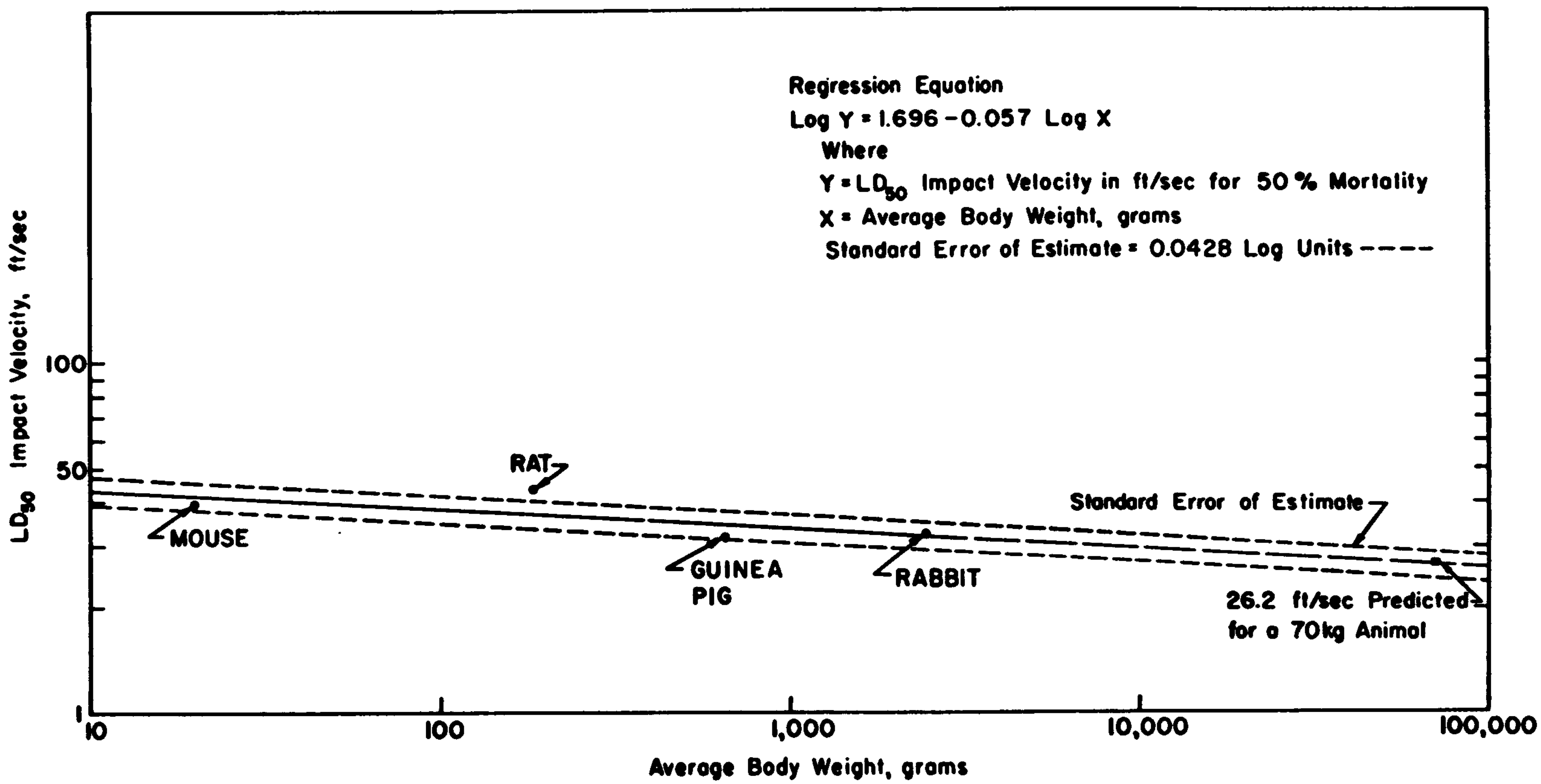

Figure 11

TABLE 5

THE RANGES OF IMPACT VELOCITIES ASSOCIATED WITH EXPERIMENTAL FRACTURE OF THE HUMAN SKULL

Range impact velocities ft/sec	Approx. velocity in mph	Approx. height of fall in.	Number of subjects	Fractures in percent
13.5-14.9	9.5	37	9	19
15-16.9	10.9	48	10	22
17-18.9	12.2	61	12	26
19-20.9	13.6	75	11	24
21-22.9	15.0	91	4	9
Total			46	100

Minimum velocity with fracture - 13.5 ft/sec (9.2 mph)

Maximum velocity with fracture - 22.8 ft/sec (15.5 mph)

Maximum velocity without fracture - unstated.

TABLE 6

TENTATIVE CRITERIA FOR TERTIARY BLAST EFFECTS

Critical organ or event	Related impact velocity ft/sec*
Total body:+	
Mostly "safe"	10
Lethality threshold	20
Lethality 50 percent	26
Lethality near-100 percent	30
Skull fracture:+	
Mostly "safe"	10
Threshold	13
50 percent	18
Near 100 percent	23

*Applies to uncontrolled impact with a hard, flat surface.

+Data from DASA 1245; Swearingen, McFadden, Garner and Blethrow; Zuckerman and Black; Gurdjian, Webster and Lissner.

"real-life" situation; namely, urban automobile fatalities as reported by DeHaven.[48] These show 40-percent lethality to be associated with estimated vehicular speeds of 20 mph or less (29 ft/sec) and 70-percent lethality with speeds of 30 mph or less (43 ft/sec). Though the figures do not necessarily apply to abrupt impact or specify the actual velocity at which body impact occurred, they do fix an upper limit. In all probability, the correspondence between the figures from the interspecies extrapolation and from the automobile accidents represents more than a happenstance.

4. General

A few general observations covering the criteria set forth above are in order. First, any biological criteria estimating human tolerance from mammalian interspecies studies must be used cautiously; there are uncertainties related to (a) how much human response "in truth" may vary from the mammalian "average," and (b) what the intraspecies variation may be for man at any specified age, including the very young and the very old.

Second, the criteria attempt to establish a quantitative relationship between biological response and a measurable environmental variation. It needs be quite clear that this variation or "dose" refers to conditions existing very close to any exposed subject and not at a distance; i.e., not outdoors if the individual is indoors, and not in the middle of a room if the person is exposed against a wall.

Finally, the criteria set forth in Tables 2 through 6 are partly extensions and modifications of similar data published elsewhere.[17, 18, 21, 28] That they are, in some instances, different from previous estimates should not be surprising. The current figures are still tentative and no doubt will be updated periodically in the future as investigative research efforts reveal new and applicable data.

III. Applications to Nuclear Explosions

A. General

Though there are uncertainties in the areas of biological response and hazards assessment, there may indeed be greater variabilities involved in attempting to relate such information to nuclear explosions. Even so, such an exercise is instructive, and it is helpful to consider a number of relevant eventualities. First, it is possible to proceed assuming that the scaled "free-field" effects parameters might approximate the environmental variations at least for certain exposure conditions; i.e., blast parameters obtained by "free-field" scaling are assumed to be unmodified by the geometry of exposure. Said another way, it is assumed that geometric scaling is not necessary. Even though this may be unrealistic, it represents an essential initial step, and interested and qualified individuals might later modify the analysis according to the dictates of geometric scaling.

Second, in some cases simple geometric scaling will be employed to help set range limits for certain hazards. For example, if one assumes an exposure condition permitting maximal reflection of overpressure, all other factors constant, this would tend to maximize the range over which a relevant effect might occur.

Third, the comparative assessment of hazards associated with exposure to blast phenomena and those due to ionizing and thermal radiation should always be kept in mind. It only makes common sense to contemplate survival as a stepwise process requiring plans to do those things first that assure survival for milliseconds, then seconds, minutes, hours and days, etc. A progression of this thinking — which "says" (a) do first what is necessary to avoid the most far-reaching immediate effect, then (b) reassess the problem and (c) repeat the process — soon allows one to know that eventually a great deal of attention must be paid to the interrelations of the major effects which occur at close range. As will be seen, this includes all the potential blast hazards.

Fourth, as will be noted briefly below, considerable data are now available to help assess the translational potential of blast phenomena for missiles and man, and therefore a helpful contribution can be set forth in the problem area termed "Secondary Events" in Table 1.

B. Translational Data

It was evident years ago that work should be carried out to establish a relationship between "free-field" blast parameters and the aerodynamic characteristics of objects that might be displaced, be they sticks, stones, frangible materials, or man. As early as 1954, plans were underway to determine theoretically and empirically what the translational velocities might be as functions of yield, range, and distance of travel* for objects having various areas, masses and drag coefficients.

During the 1955 and 1957 test series over 20,000 missiles were trapped in a way that allowed their impact velocities to be determined[3, 4, 22, 29] under a variety of exposure conditions for explosive yields that ranged from about 10 to 40 kt. Also the translation of anthropometric dummies was studied.[14] A mathematical model was designed using the empirical data as a guide. The model is now available for predicting the translation of objects as tiny as small slivers of glass and as large as adult man.[23, 24] Though the model only applies strictly to ideal wave forms and only has been validated empirically for 10- to 40-kt yields, it nevertheless allows one to tie translational data known to be biologically hazardous to blast parameters which in turn can be related to explosive yield and range through the scaling laws.

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*Distance of travel refers to the blast-induced translation of an object. It is important because in gaining velocity an object moves over a finite distance in a finite time. Hence, velocity achieved — up to a maximum — increases with both translational distance and time.

C. Prediction of Potential-Hazards Ranges

Examples will now be presented in detail making use of the analytical criteria previously mentioned and the "free-field" scaling laws. Initially, and except where noted, this exercise will be limited to a 20-Mt surface burst at sea level.

1. Primary Blast

For the 20-Mt surface burst, Table 7 shows the ranges over which specified primary blast hazards might be expected. "Safe" distances are noted as well as the range inside which eardrum failure, lung damage and lethality might occur. Also, the table shows the levels of initial nuclear and thermal radiation that can be predicted for the ranges shown using the "free-field" scaling laws. Thermal fluxes were computed in duplicate, one series for a 50-mi, the other for a 10-mi visibility.

It is evident that the potential for primary blast damage to personnel may extend as far from ground zero as 7 to 12 mi for the ear, 4 to 7 mi for lung injury, and 3 to 5 mi for lethality, depending upon whether the conditions of exposure do or do not allow maximal reflection of the "free-field" incident overpressure.

2. Secondary Blast

Table 8 similarly sets forth the predicted ranges inside of which 10-gm glass fragments* would have the specified velocities and, hence, might produce the noted secondary blast hazards. The procedures used assumed that a given structure faced the blast wave and that the overpressures would undergo reflection; the range data were so computed. This was done because the Nevada experience showed frangible material mounted in the wall of exposed structures behaved in accordance with the reflected pressure and not as material mounted in the open. Also, it must be pointed out that the calculations were made arbitrarily for a translational distance of 10 ft. Data available, however, allow computations for other desired distances of missile travel as well as for other types of debris providing the acceleration coefficient+ is known or can be determined.

It is evident that the range for possible injury from missiles reaches out to 20 mi, a distance much greater than the most far-reaching primary blast hazard — ear damage at 12 mi. The latter, however, is about the same as is the maximal range of 12 mi for the threshold of serious penetrating wounds due to missiles.

Table 9 presents range data and related effects parameters for the criteria applicable to injury from the impact of a 10-lb blunt object with

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*Applies to double-strength window glass.

+Acceleration coefficient, $a = \frac{A}{m} \cdot C_d$; A = area presented to the wind; m = mass; C_d = drag coefficient.

TABLE 7

RANGE FOR SPECIFIED PRIMARY BLAST HAZARDS AND ASSOCIATED FREE-FIELD EFFECTS PARAMETERS* – 20-MT SURFACE BURST AT SEA LEVEL

Biological event	Incident maximum overpressure, Reflection	psi	Range, mi	Initial nuclear radiation,** rems	Thermal radiation (50-mi visibility), cal/cm^2	Thermal radiation (10-mi visibility), cal/cm^2
Eardrum failure:						
Threshold	no	5	7.5	< 1	200	130
	yes	2.3	12	< 1	70	42
Lung damage:						
Threshold	no	15	4.2	< 1	700	500
	yes	6.4	6.6	< 1	260	180
Lethality:						
Threshold	no	30-42	3.0-2.6	2.5-23	1400-1900	1100-1500
	yes	12-15	4.7-4.2	< 1	540- 700	380- 500
50 percent	no	42-57	2.6-2.2	23-180	1900-2500	1500-1900
	yes	15-19	4.2-3.8	< 1	700- 850	500- 620
Near 100 percent	no	58-80	2.2-1.9	350-2300	2700-3700	2100-3000
	yes	19-25	3.8-3.3	< 1	850-1100	620- 860

*Free-field scaling according to The Effects of Nuclear Weapons, Revised Edition.

**Computed for an air density ratio, ρ/ρ_o, of 1.0.

TABLE 8

RANGE FOR SPECIFIED SECONDARY BLAST HAZARDS AND ASSOCIATED FREE-FIELD EFFECTS PARAMETERS* – 20-MT SURFACE BURST AT SEA LEVEL

Biological event	Velocity for 10-gm glass fragment,** ft/sec	Range, mi	Maximum incident overpressure, psi	Initial nuclear radiation,+ rems	Thermal radiation (50-mi visibility), cal/cm^2	Thermal radiation (10-mi visibility), cal/cm^2
Skin laceration:						
Threshold	50	20	1.0	< 1	21	11
Serious wounds:						
Threshold	100	12	2.3	< 1	70	42
50 percent	180	8.8	3.8	< 1	140	88
Near 100 percent	300	6.6	6.4	< 1	260	180

*Free-field scaling according to The Effects of Nuclear Weapons, Revised Edition. Velocity-range relations from The Effects of Nuclear Weapons, Revised Edition, and CEX-58.9.

**Velocity reached at a displacement of 10 ft for 10-gm double-strength window-glass fragment. Acceleration coefficient, α, of 10-gm fragment = 0.72 sq ft/lb.

+Computed for an air-density ratio, ρ/ρ_o, of 1.0.

TABLE 9

RANGE FOR SPECIFIED SECONDARY BLAST HAZARDS AND ASSOCIATED FREE-FIELD EFFECTS PARAMETERS – 20-MT SURFACE BURST AT SEA LEVEL*

Biological event	Velocity for 10-lb stone** ft/sec	Range mi	Maximum incident overpressure, psi	Initial nuclear radiation, + rems	Thermal Radiation (50-mi visibility), cal/cm^2	Thermal Radiation (10-mi visibility), cal/cm^2
Cerebral concussion:						
Mostly "safe"	10	16	1.4	< 1	36	20
Threshold	15	14	1.8	< 1	49	29
Skull fracture:						
Mostly "safe"	10	16	1.4	< 1	36	20
Threshold	15	14	1.8	< 1	49	29
Near 100 percent	23	12	2.3	< 1	72	44

*Free-field scaling according to The Effects of Nuclear Weapons, Revised Edition.

Range-velocity relations from The Effects of Nuclear Weapons, Revised Edition, and CEX-58.9.

**Maximum velocity attained. Acceleration coefficient, α, of 10-lb stone = .02 sq ft/lb.

+Computed for an air-density ratio, ρ/ρ_o, of 1.0.

the human head. It is clear that within a range of 16 mi the potential exists for this type of secondary blast injury.

3. Tertiary Blast

a. 20-Mt Surface Burst at Sea Level

The ranges for the various potential hazards from dynamic decelerative impact and the other associated effects parameters are set forth in Table 10 for the 20-Mt surface burst at sea level. Velocity computations were made for a translational distance of 10 ft. The acceleration coefficient employed was 0.03 ft^2/lb which applies to an average adult man in random orientation. This happens to be a figure between the acceleration coefficient for an individual exposed face-on and side-on to the blast wave. Note that the mostly "safe" range is as far as 14 mi from ground zero. Much inside this distance, the incidence of impact injury can be expected to rise.

b. Maximizing Burst Heights — 20 Mt

As an example of how variation in the burst height might influence the prediction of the hazard range, Table 11 was prepared. Computations were made for those burst heights which would maximize the range of the overpressures associated with the specified translational velocities. Translational distance was "fixed" at 10 ft. The associated nuclear- and thermal-radiation data were scaled on a slant-range basis, but corrected to the ground range shown.

For the "maximizing" burst condition the mostly "safe" range is predicted to be 25 mi from ground zero, 11 mi farther than for the surface burst. It is interesting also to point out that the burst conditions which maximize the ranges of the tertiary blast hazards tend to lower the "free-field" levels of both nuclear and thermal radiation. A comparison of the last two columns of Tables 10 and 11 show that thermal fluxes may decrease two to fourfold.

c. The Velocity Displacement Relationship — Sea-Level Burst of 20 Mt

Placing a constraint of 10 ft upon displacement distance, as was done in the computations noted above, does not allow full appreciation of the displacement potential of the long-duration blast winds associated with high explosive yields. To illustrate better the possible human hazard, Figure 12 was prepared showing the displacement velocity as a function of distance of travel for specified overpressures applicable to a 20-Mt yield exploded at the surface at sea level. It is clear that distances of travel between about 100 and 1000 ft are required before maximal velocities of between about 15 and 500 ft/sec would be reached for overpressures varying from 1.5 to 25 psi.

Figure 12 is also useful in another way; it allows one to contemplate displacement hazards in terms of the dimension of work space or in terms of distance from a decelerating surface such as a wall. For

TABLE 10

RANGE FOR SPECIFIED TERTIARY BLAST HAZARDS AND ASSOCIATED FREE-FIELD EFFECTS PARAMETERS – 20-MT SURFACE BURST AT SEA LEVEL*

Biological event+	Velocity for 165-lb man,** ft/sec	Range mi	Maximum incident overpressure psi	Initial nuclear radiation,++ rems	Thermal radiation, (50-mile visibility), cal/cm^2	Thermal radiation, (10-mile visibility), cal/cm^2
Total body impact:						
Mostly "safe"	10	14	1.8	<1	49	28
Lethality:						
Threshold	20	9.6	3.3	<1	110	72
50 percent	26	8.4	4.1	<1	150	99
Near 100 percent	30	7.8	4.8	<1	190	120
Skull fracture:						
Mostly "safe"	10	14	1.8	<1	49	28
Threshold	13	12	2.3	<1	70	42
50 percent	18	10	3.1	<1	100	67
Near 100 percent	23	9.0	3.7	<1	130	84

*Free-field scaling according to The Effects of Nuclear Weapons, Revised Edition. Velocity-range relations from The Effects of Nuclear Weapons, Revised Edition, and CEX-58.9.

+Applies to uncontrolled impact with a hard flat surface.

**Velocity reached after a displacement of 10 ft. Average acceleration coefficient, α, of 165-lb tumbling man = .03 sq ft/lb.

++Computed for an air-density ratio, ρ/ρ_o, of 1.0.

TABLE 11

RANGE FOR SPECIFIED TERTIARY BLAST HAZARDS AND ASSOCIATED FREE-FIELD EFFECTS OF PARAMETERS – 20-MT BURSTS AT HEIGHTS ABOVE SEA LEVEL TO MAXIMIZE THE GROUND RANGE OF THE BLAST PARAMETERS SHOWN*

Biological event+	Velocity for 165-lb man,** ft/sec	Ground range, mi	Maximum incident overpressure psi	Initial nuclear radiation,++ rems	Thermal radiation, (50-mile visibility), cal/cm^2	Thermal radiation, (10-mile visibility), cal/cm^2
Total body impact:						
Mostly "safe"	10	25	1.6	<1	15	7
Lethality:						
Threshold	20	16	3.3	<1	41	22
50 percent	26	14	3.9	<1	55	33
Near 100 percent	30	12	4.8	<1	78	47
Skull fracture:						
Mostly "safe"	10	25	1.6	<1	15	7
Threshold	13	21	2.2	<1	22	11
50 percent	18	17	2.9	<1	38	21
Near 100 percent	23	15	3.5	<1	50	29

*Free-field scaling according to The Effects of Nuclear Weapons, Revised Edition. Velocity-range relations from The Effects of Nuclear Weapons, Revised Edition, and CEX-58.9.

+Applies to uncontrolled impact with a hard flat surface.

**Velocity reached after a displacement of 10 ft. Average acceleration coefficient, α, of 165-lb tumbling man = .03 sq ft/lb.

++Computed for an air-density ratio, ρ/ρ_o, of 0.9.

VELOCITY vs. DISPLACEMENT for 165-lb MAN-20-MT SEA-LEVEL SURFACE BURST
COMPUTED for ACCELERATION COEFFICIENT=.03 sq ft/lb; p_0=14.7 psi; c_0=1117 ft/sec

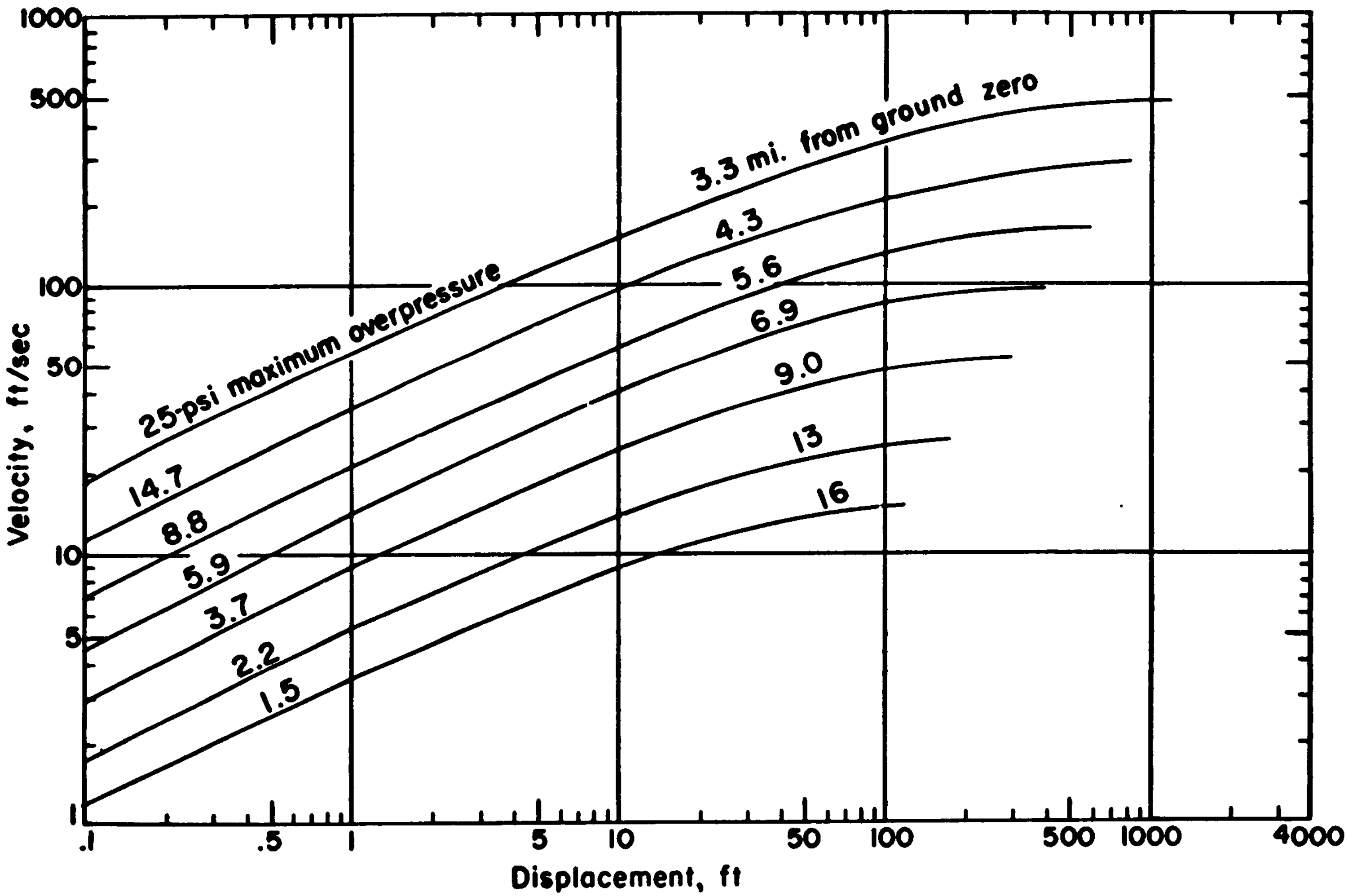

Figure 12

example, only a foot of travel is required to reach the skull-fracture threı hold of 13 ft/sec if the overpressure is between 5 and 6 psi. The associate range for these overpressures is about 6.8 to 7.5 mi.

4. Summary of Comparative Effects Data for 20-Mt Sea-Level Surface Burst

It is instructive to study the blast-hazard data for the 20-Mt sea-level surface burst as a function of increasing range from ground zero This allows a comparative perspective to be developed which is more mear ingful if other effects parameters also are included as has been done in Table 12. From top to bottom, the figures in the range column show pro-gressively increasing ranges inside of which the specified biological effect or event can be expected. Data from The Effects of Nuclear Weapons[1] weı used to scale the crater and fireball radii and the ranges for initial nuclea and thermal radiation. The nuclear-radiation threshold dose was assumed to be 100 rems for emergency conditions. Thermal radiation was compute for 10- and 50-mi visibilities; 4 and 10 cal/cm^2 were used as the values associated, respectively, with first- and second-degree burns of the expos white skin.

Table 12 illustrates very well the fact that primary, seconda: and tertiary blast effects may produce injury over considerable ranges fro ground zero. Their relative importance compared with thermal and initia nuclear radiation also is indicated, but in reality assessment needs be ma in terms of exposure conditions. For example, lethality threshold for pri mary blast may range from 3 to 5 mi from ground zero. At these distance initial ionizing radiation apparently would be no problem even if the scaled doses were increased by factors of 10. Thermal fluxes, however, might range from 380 to 1400 cal/cm^2, which could or could not represent an immediate hazard to personnel depending upon conditions of exposure.

Definitive information regarding relevant geometric scaling i not at hand. It is not, however, just academic to note two things: First, the Nevada Test Site in 1957, mammals were recovered from underground closed shelters located 840 ft (0.16 mi) from a 700-ft tower on which a 43- burst was detonated. The slant range, about 0.2 mi, is about equal to the predicted maximal fireball radius. There were no thermal problems insi the shelter.[19, 49]

Second, living mammals were recovered in 1955 and 1957 from underground structures tested with open entryways.[6, 16] In one in-stance the "free-field" thermal fluxes were well over 500 cal/cm^2. The majority of the species exposed exhibited only mild singeing of the fur, th those located close to the main entryway were severely burned, apparentl hot gases and dust carried into the structure by the blast wave. Though th matters are little understood,[50-52] it is clear that considerable thermal p tection from direct thermal radiation can occur at certain locations inside appropriate structures even if they are open at burst time.

TABLE 12

COMPARATIVE BIOLOGICAL EFFECTS AS A FUNCTION OF RANGE FOR 20-MT SURFACE BURST AT SEA LEVEL

Biological event or effect	Range mi	Maximum incident overpressure psi	Initial nuclear radiation* rems	Thermal radiation 50-mile visibility cal/cm^2	Thermal radiation 10-mile visibility cal/cm^2
Crater: inside radius, dry soil	.33	> 200	> 10^7	> 10^5	> 10^5
Crater: outside radius, dry soil	.65	> 200	> 10^7	3900	3000
Initial nuclear radiation: injury, threshold	2.4	50	100	2300	1800
Fireball radius, maximum	2.6	42	23	1900	1500
Primary blast: lethality, threshold — without pressure reflection	3.0	30	2.5	1400	1100
Lung damage, threshold — without pressure reflection	4.2	15	< 1	700	500
Primary blast: lethality, threshold — maximum pressure reflection	4.7	12	< 1	540	380
Lung damage, threshold — maximum pressure reflection	6.6	6.4	< 1	260	180
Eardrum failure, threshold — without pressure reflection	7.5	5.0	< 1	200	130
Impact injury: lethality, threshold+	9.6	3.3	< 1	110	72
Eardrum failure, threshold — maximum pressure reflection	12	2.3	< 1	70	42
Impact injury: skull fracture, threshold+	12	2.3	< 1	70	42
Serious wounds from 10-gm glass fragments, threshold+	12	2.3	< 1	70	42
Impact injury, threshold+	14	1.8	< 1	49	28
Skin lacerations from 10-gm glass fragments, threshold+	20	1.0	< 1	21	11
Skin burns — second degree, 10-mi visibility	21	0.95	< 1		10
Skin burns — second degree, 50-mi visibility	28	0.64	< 1	10	
Skin burns — first degree, 10-mi visibility	29	0.60	< 1		4
Skin burns — first degree, 50-mi visibility	41	0.37	< 1	4	
Window glass fails	130	0.1	< 1	< 1	< 1

*Computed for an air-density ratio, ρ/ρ_0, of 1.0.
+After 10 ft of travel.

5. The Range-Yield Relationship for Biological Blast Effects

To further illustrate the application of the biological blast criteria to nuclear explosions, charts were prepared showing the range-yield relationship for each blast effect.

a. Primary Blast

For example, Figure 13 graphically presents the primary blast data for sea-level surface bursts for yields ranging from 1 kt to 100 Mt. The bottom four curves show range as a function of yield for the indicated incident overpressures assuming no pressure reflection. The top four curves give the same data except that maximal reflection of overpressure was assumed; e.g., 2.3 psi will reflect to 5 psi, 6.4 to 15 psi, etc.

b. Secondary and Tertiary Effects

Figures 14 and 15 similarly show the ranges inside which the indicated missile and displacement hazards, respectively, can be expected for sea-level surface bursts varying in yield from 1 kt to 100 Mt.

c. Comparative Threshold Data

Using the threshold criteria for eardrum failure, for lung injury (both with and without maximum pressure reflection), for skin lacerations, and for gross body impact, Figure 16 was prepared to illustrate how the comparative ranges of the several blast effects vary with explosive yield. It is clear from the different slopes of the curves that the relative ranges for the different blast effects vary significantly with yield. This is particularly evident for the displacement data for man.

Finally, Figure 17 allows one to assess, on the "free-field" basis at least, the range-yield values for initial nuclear and thermal radiation compared with the most far-reaching as well as the most significant blast effects. Only three comments will be offered here.

First, the data indicate that even for explosive yields as low as 10 kt, secondary and tertiary blast effects have a very important casualty potential. Second, for yields above 100 kt, primary, secondary and tertiary blast effects are comparatively quite significant.

Third, for yields of 1 Mt and above, all blast effects are strong competitors for the attention of perceptive individuals interested in the relative hazards from all the major weapons effects. Indeed, for persons exposed indoors and shielded from direct thermal radiation, secondary and tertiary blast effects almost certainly represent the major causes for early lethality and serious injury from nuclear explosions. Further — and in fact particularly at the closer ranges — primary blast damage, embodying an unequivocal and highly dangerous capability for producing acute death, also deserves the highest respect by all responsible persons who would achieve a sound and balanced appreciation of the biological effects of nuclear weapons.

RANGE-YIELD RELATIONSHIP for
INDICATED PRIMARY BLAST DAMAGE; SEA-LEVEL SURFACE BURSTS

Applies to Fast-rising Overpressures with Ideal or Near-ideal Wave Forms

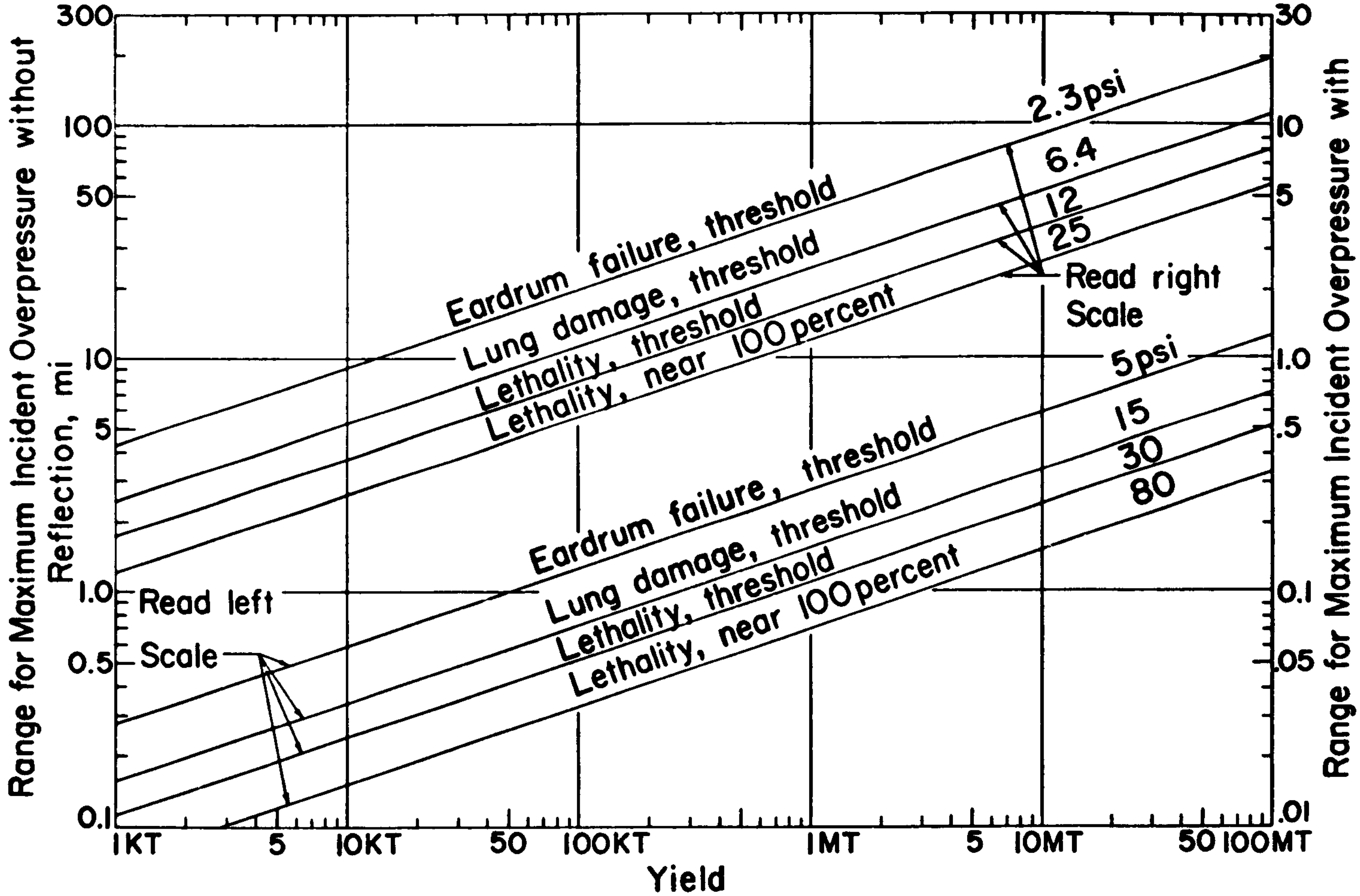

Figure 13

RANGE-YIELD RELATIONSHIP for INDICATED SECONDARY BLAST DAMAGE from 10-gm WINDOW-GLASS FRAGMENTS* for SEA-LEVEL SURFACE BURSTS

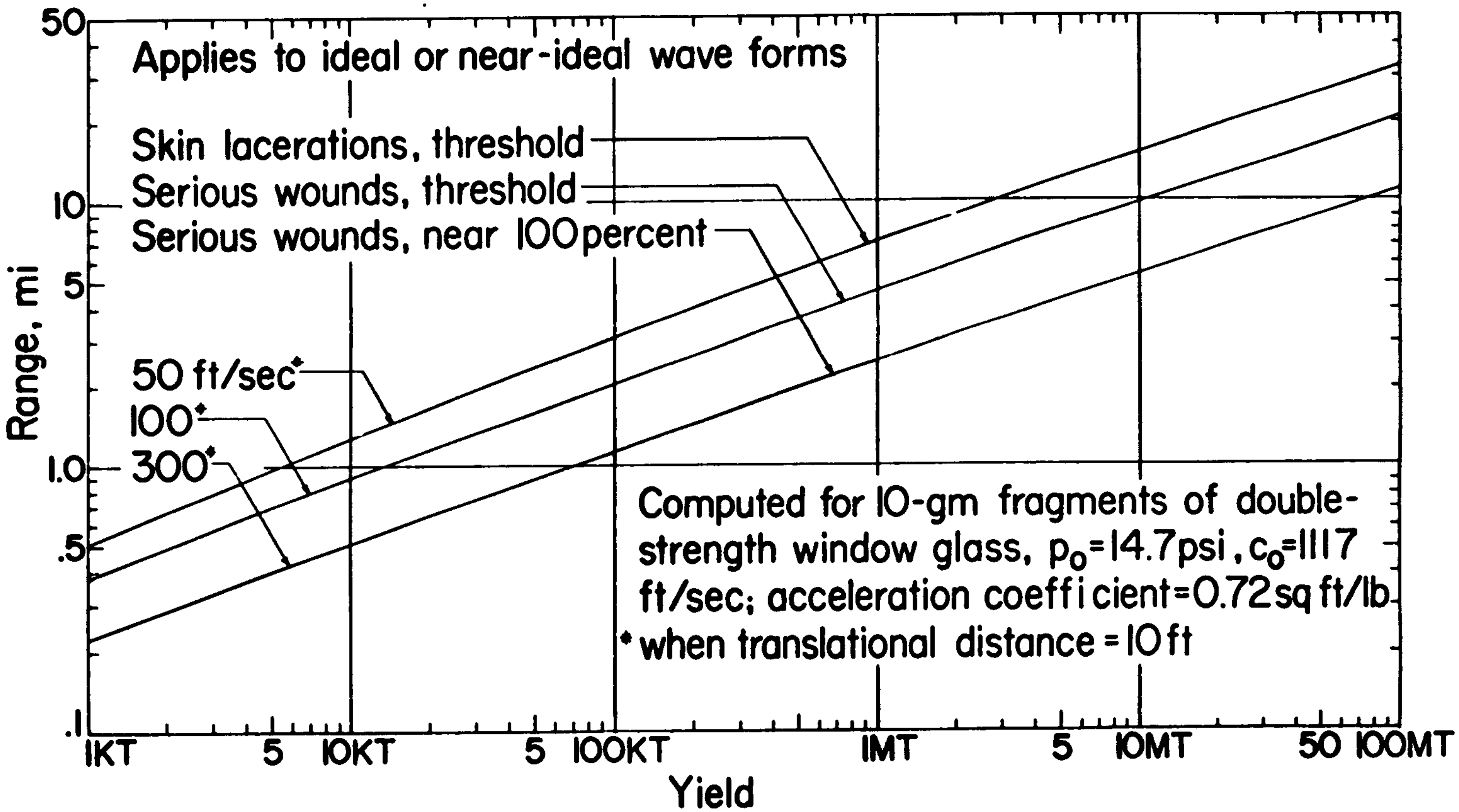

Figure 14

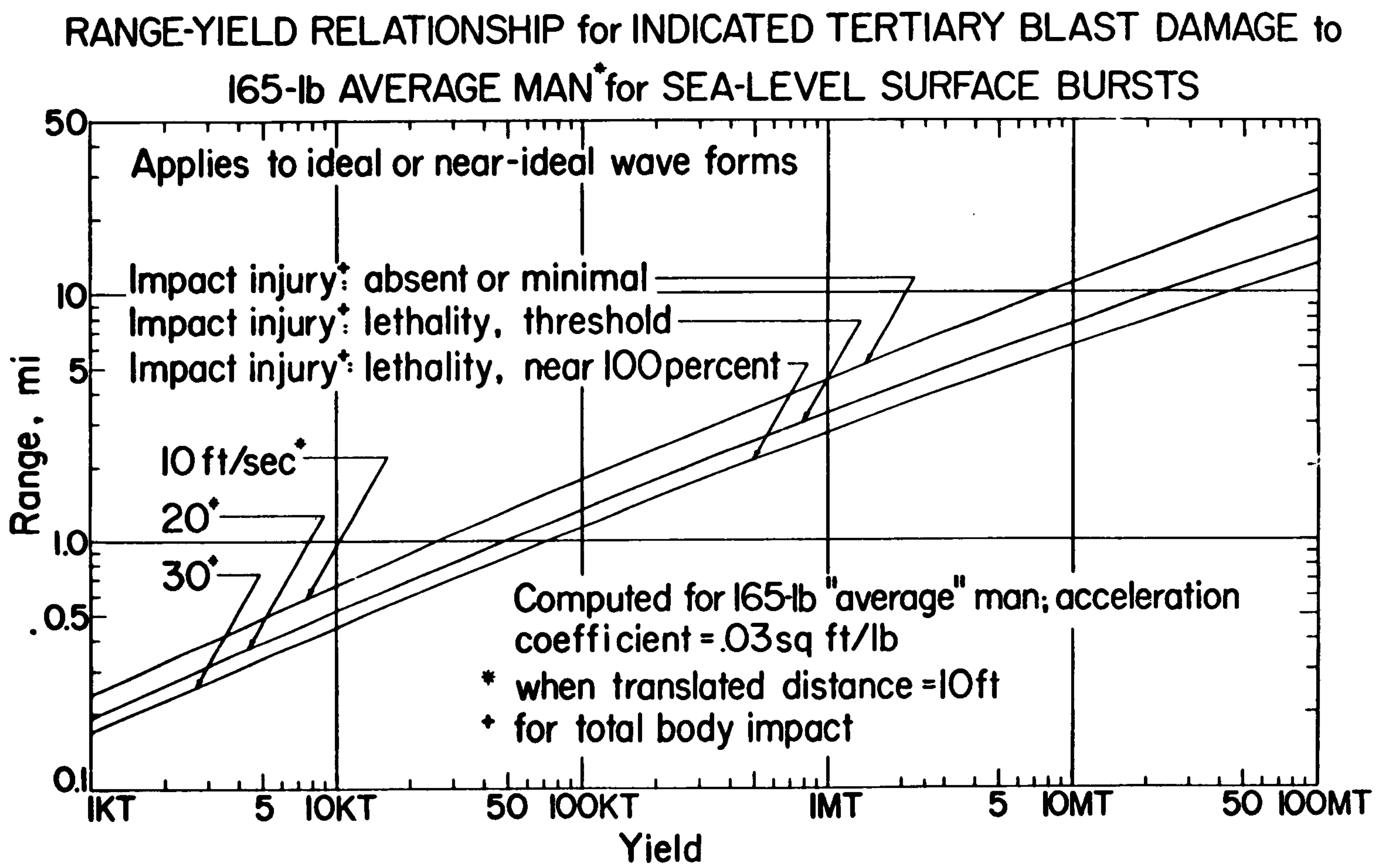
RANGE-YIELD RELATIONSHIP for INDICATED TERTIARY BLAST DAMAGE to 165-lb AVERAGE MAN* for SEA-LEVEL SURFACE BURSTS
Applies to ideal or near-ideal wave forms
Impact injury+: absent or minimal
Impact injury+: lethality, threshold
Impact injury+: lethality, near 100 percent
10 ft/sec*
20*
30*
Computed for 165-lb "average" man; acceleration coefficient = .03 sq ft/lb
* when translated distance = 10 ft
+ for total body impact
Range, mi
50
10
5
1.0
0.5
0.1
1KT
5
10KT
50
100KT
1MT
5
10MT
50
100MT
Yield

Figure 15

COMPARATIVE-EFFECTS DATA SHOWING RANGES INSIDE WHICH INDICATED BIOLOGICAL BLAST RESPONSES MAY OCCUR for SEA-LEVEL SURFACE BURSTS

Applies to Fast-rising Pressures with Ideal or Near-ideal Wave Forms

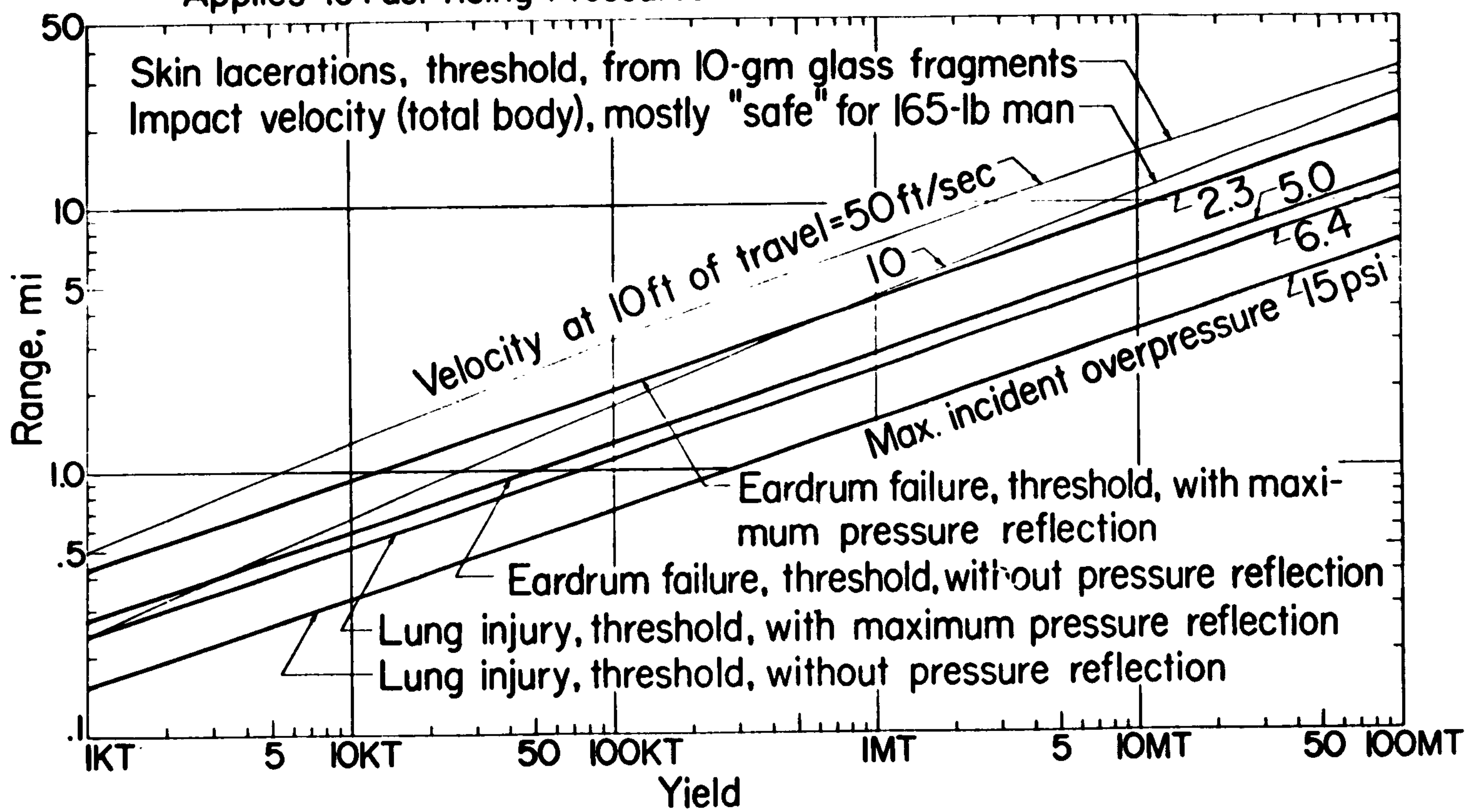

Figure 16

COMPARATIVE-EFFECTS DATA SHOWING RANGES INSIDE WHICH INDICATED BIOLOGICAL RESPONSES MAY OCCUR for SEA-LEVEL SURFACE BURSTS

Applied to Ideal or Near-ideal Wave Forms

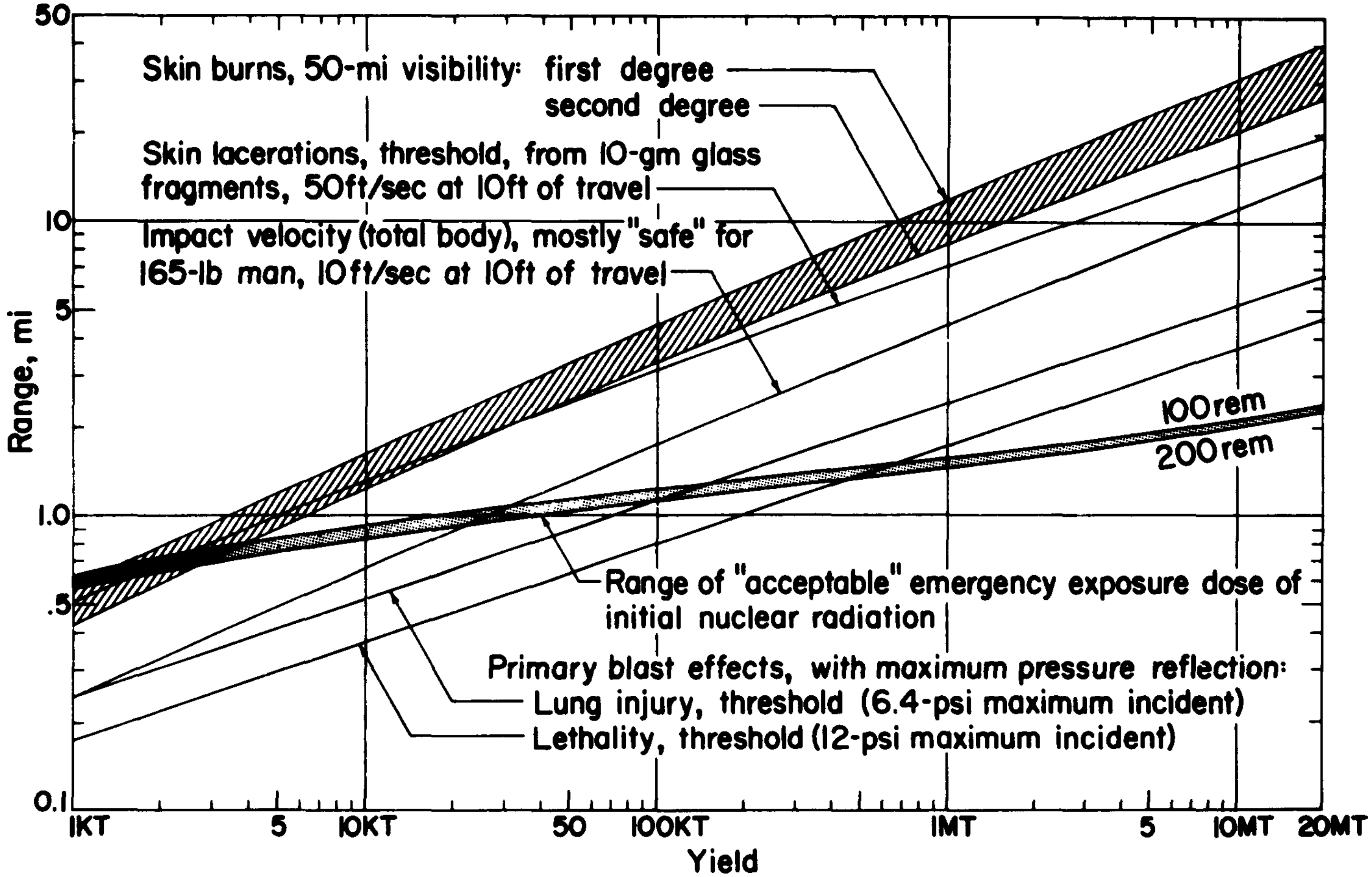

Figure 17

1957 of buried structures at 245 psi,[53] the design of underground shelters exposed in 1957 at 170 psi[49] from which living mice were recovered,[19] the successful performance in 1955 of buried shelters at about 90 psi,[52] the recovery in 1955 of living mammals from a modification of these employed without doors to study blast effects,[6] and biological experiments in 1953 indicating survival in buried long-tubular structures of simple design and with open entryways at about 15 psi.[2]

These and other data indicate that protection against blast — indeed against all major weapons effects — is technically feasible at least at the 200 psi level. This statement is written knowing full well that the 200 psi range from a 20 Mt sea-level surface burst is about 1.3 mi,[1] a distance outside the scaled crater lip at near 0.7 mi[1] and inside the maximal fireball radius of 2.6 mi.[1]

In closing I wish to quote an appropriate passage from a paper published a few years ago:[18]

> "Last but with equal simplicity, those who contemplate the physics and biology of blast effects and succeed in relating such information to modern, large-scale explosives, will know that prevention and prophylaxis comprise the course of sagacity. Too, those who have used vaccination along with epidemiologic and sanitary principles in support of sound clinical care to save the sick and gain long term control of communicable disease, understand the impact of knowledge and action contrasted with the futility of hoping a given epidemic would just disappear. Nuclear explosives are with us today and will not just disappear. The world after 1945, the year the first atomic explosion occurred in New Mexico, is not the same as it was before. Times have changed. So also must the habits of man. Even now the future is measuring the adaptability of people and societies the world over. For sure, only the most flexible will survive."

SUMMARY

A summary of the material presented in this communication follows:

1. By way of introduction it was pointed out that:

(a) Air blast could be hazardous because of injuries due directly or indirectly to blast pressures, winds and the interaction of these phenomena with animate objects and with materials comprising the exposure environment;

(b) Biological blast effects were divided into the following categories; primary effects due to variations in environmental pressure; secondary effects due to the impact of blast-energized debris; tertiary effects that occur as a consequence of gross bodily displacement; and miscellaneous effects encompassing exposure to dust, non-line-of-sight thermal phenomena such as hot gases and debris and blast-induced fires;

(c) Interested individuals who would think about biological effects of nuclear weapons should direct attention to several problem areas; viz., "free-field" and geometric scaling, secondary events, etiologic mechanism, biological response and hazards assessment and biomedical tasks;

(d) The objectives of the presentation would be selectively limited to a discussion of the nature of blast-produced injuries, the development of criteria for different levels of biological response and the application of these criteria to nuclear explosions.

2. Primary blast damage to the lung was noted as an outstanding critical lesion responsible for subsequent development of arterial air emboli, pulmonary hemorrhage and edema and the rapid and high lethality characteristic of the primary blast syndrome. Also, it was noted that lethality can be delayed as long as 17 days in mammals.

3. That damage from penetrating and nonpenetrating blast-energized missiles was in many ways similar to war wounds from fragments and projectiles was pointed out, as was the serious nature of penetrations into serous cavities or injuries to critical organs, which in the latter case might be rapidly fatal.

4. Although tertiary blast damage associated with whole-body displacement might occur from accelerative or decelerative events, the overriding importance of the latter was noted. Interspecies mammalian studies of the effects of impact with a hard surface were described to illustrate that rapid and early lethality also characterizes the impact syndrome.

5. The unequivocal and highly dangerous character of blast-produced lesions and the need for timely and expert medical care were cited to emphasize the desirability of avoiding, preventing or sharply minimizing blast injuries.

6. Tentative biological criteria applicable to blast-produced events occurring very close to a human target were set forth as follows:

(a) For want of data applicable to atypical wave forms, the primary blast criteria were limited to typical "fast"-rising overpressures of long duration. They were:

Eardrum failure threshold	5 psi
Lung damage threshold	15 psi
Lethality threshold	30-42 psi
Lethality near 50 percent	42-57 psi
Lethality near 100 percent	58-80 psi

(b) Secondary blast criteria were arbitrarily established for a 10-gm glass fragment and a 10-lb blunt object impacted with the head. They were:

Penetrating missiles

Skin-laceration threshold	50 ft/sec
Serious-wound threshold	100 ft/sec
Serious wounds near 50 percent	180 ft/sec
Serious wounds near 100 percent	300 ft/sec

Nonpenetrating missiles

Mostly "safe"	10 ft/sec
Concussion threshold	15 ft/sec
Skull fracture threshold	15 ft/sec
Skull fracture near 100 percent	23 ft/sec

(c) Tertiary blast criteria were arbitrarily established for decelerative impact with a hard flat surface involving the head and the whole body. They were:

Mostly "safe"	10 ft/sec
Skull fracture threshold	13 ft/sec
Skull fracture near 50 percent	18 ft/sec
Lethality threshold (whole body)	20 ft/sec
Skull fracture near 100 percent	23 ft/sec
Lethality near 50 percent (whole body)	26 ft/sec
Lethality near 100 percent (whole body)	30 ft/sec

7. The criteria were applied to nuclear explosions through use of the "free-field" scaling laws and employment of a recently developed mathematical model for predicting from blast parameters the translational velocities of different objects. Translational velocities were computed at displacement distances of 10 ft in all but noted instances. The predicted maximal ranges inside which the specified biological blast effects could be expected were computed for a 20-Mt sea-level surface burst. These ranges were:

Skin laceration threshold	20 mi
Impact injury mostly "safe"	14 mi
Serious missile wound threshold	12 mi
Impact injury, skull fracture threshold	12 mi
Eardrum failure threshold (maximum pressure reflection)	12 mi
Skull fracture near 50 percent	10 mi
Impact injury, lethality threshold (whole body)	9.6 mi
Skull fracture near 100 percent	9.0 mi
Impact lethality near 50 percent	8.4 mi
Impact lethality near 100 percent	7.8 mi
Eardrum failure threshold (no pressure reflection)	7.5 mi
Lung damage threshold (maximum pressure reflection)	6.6 mi
Primary blast lethality threshold (maximum pressure reflection)	4.7 mi
Lung damage threshold (no pressure reflection)	4.2 mi
Primary blast lethality near 100 percent (maximum pressure reflection)	3.0 mi
Primary blast lethality threshold (no pressure reflection)	3.0 mi
Primary blast lethality near 50 percent (no pressure reflection)	2.6 mi
Primary blast lethality near 100 percent (maximum pressure reflection)	2.2 mi

8. To illustrate how much burst height could increase the range of blast effects, computations using the tertiary blast criteria were made for a 20-Mt explosion burst at those heights that would maximize the ground range of these blast effects; the comparative figures were:

	Maximizing burst heights	Surface burst sea level
Impact injury mostly "safe"	25 mi	14 mi
Skull fracture threshold	21 mi	12 mi
Skull fracture near 50 percent	17 mi	10 mi
Impact lethality threshold (whole body)	16 mi	9.6 mi
Skull fracture near 100 percent	15 mi	9.0 mi
Impact lethality near 50 percent (whole body)	14 mi	8.4 mi
Impact lethality near 100 percent (whole body)	12 mi	7.8 mi

9. Graphic data were presented for the 20-Mt sea-level surface burst to show how man's displacement velocity increases with translational distance. In approximate numbers the data were:

Displacement distance ft	Velocity in ft/sec	Associated maximum overpressure psi	Range in mi
1	3.4-19	1.5-25	16-3.3
10	9-150	1.5-25	16-3.3
100	14-350	1.5-25	16-3.3
120	15 (max)	1.5	16
180	27 (max)	2.2	13
300	55 (max)	3.7	9
425	100 (max)	5.9	6.9
600	160 (max)	8.8	5.6
850	300 (max)	14.7	4.3
1200	500 (max)	25	3.3

10. The biological criteria were graphically presented to show the ranges inside which the several specified effects might occur for yields ranging from 1 kt to 100 Mt scaled for sea-level surface bursts.

11. To allow comparison of blast with other effects, doses of initial nuclear radiation and fluxes of thermal radiation were computed and tabulated, using the "free-field" scaling laws, for those ranges inside which the specified biological blast effect could be expected. For the same purpose the yield-range relationships for first- and second-degree burns and for 100 and 200 rem doses of initial nuclear radiation were compared graphically with those for several biological blast effects.

12. The results of the study were briefly discussed, and though the biological criteria employed were noted as tentative, incomplete and in need of future extension and refinement, their application to nuclear explosions as a function of yield and range clearly indicated that blast hazards must be regarded as a major cause of injury and fatality if there ever were a nuclear war.

13. Also, the desirability of avoiding exposure to blast phenomena was emphasized. Mentioned as possible alternatives for accomplishing this were diplomatic, political, military and domestic approaches and policies as well as highly important technical considerations.

14. Among the latter were the architectural and engineering principles that made experiments possible at the Nevada Test Site indicating protection up to 200 psi was technically feasible.

REFERENCES

1. Glasstone, Samuel, Editor, The Effects of Nuclear Weapons, Revised Edition 1962, Superintendent of Documents, U. S. Printing Office, Washington, D. C., April 1962.

2. Roberts, J. E., C. S. White and T. L. Chiffelle, Effects of overpressures in group shelters on animals and dummies. Operation Upshot-Knothole, Report WT-798.

3. Bowen, I. G., D. R. Richmond, M. B. Wetherbe and C. S. White, Biological effects of blast from bombs. Glass fragments as penetrating missiles and some of the biological implications of glass fragmented by atomic explosions. USAEC Report AECU-3350, Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico, June 18, 1956 (published in 1957).

4. Bowen, I. G., A. F. Strehler and M. B. Wetherbe, Distribution and density of missiles from nuclear explosions. Operation Teapot Report, WT-1168, December 1956.

5. Hirsch, F. G., Joan Longhurst, D. R. McGiboney and H. H. Sander, The effects of noise in blast-resistant shelters. Operation Teapot Report, WT-1180, June 25, 1957.

6. White, C. S., T. L. Chiffelle, D. R. Richmond, W. H. Lockyear, I. G. Bowen, V. C. Goldizen, H. W. Merideth, D. E. Kilgore, B. B. Longwell, J. T. Parker, F. Sherping and M. E. Cribb, The biological effects of pressure phenomena occurring inside protective shelters following nuclear detonation. Operation Teapot Report, WT-1179, October 28, 1957.

7. Richmond, D. R., M. B. Wetherbe, R. V. Taborelli, T. L. Chiffelle and C. S. White, The biologic response to overpressure. I. Effects on dogs of five- to ten-second duration overpressures having various times of pressure rise. J. Aviat. Med., 28: 447-460, 1957.

8. White, C. S., M. B. Wetherbe and V. C. Goldizen, The internal environment of underground structures subjected to nuclear blast. I. The occurrence of dust. Operation Plumbbob Preliminary Report, ITR-1447, November 22, 1957.

9. Taborelli, R. V. and I. G. Bowen, Tertiary effects of blast - displacement. Operation Plumbbob Preliminary Report, ITR-1469, December 20, 1957.

10. Richmond, D. R. and R. V. Taborelli, Some results of a shock tube for biomedical investigation. pp. 56-69 of Proceedings of Second Shock Tube Symposium, 5-6 March 1958, SWR-TM-58-3, Hqs. Air Force Special Weapons Center, ARDC, Kirtland Air Force Base, New Mexico.

11. White, C. S., Blast biology - A summary. A contribution to the Holifield Subcommittee Hearings, May 1, 1958. Published in Report of Hearings before a Subcommittee on Government Operations, House of Representatives, Part I - Atomic Shelter Tests, pp. 80-93, U. S. Government Printing Office, Washington, D. C., 1958.

12. Richmond, D. R., R. V. Taborelli, F. Sherping, M. B. Wetherbe, R. T. Sanchez, V. C. Goldizen and C. S. White, Shock tube studies of the effects of sharp-rising, long-duration overpressures on biological systems. AF Document SWR-TM-59-2, pp. 171-194, Proceedings of Third Shock Tube Symposium, 10-12 March 1959, Hqs, Air Force Special Weapons Center, ARDC, Kirtland Air Force Base, New Mexico.

13. Richmond, D. R., R. V. Taborelli, F. Sherping, M. B. Wetherbe, R. T. Sanchez, V. C. Goldizen and C. S. White, USAEC Report TID-6056, Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico, March 10, 1959.

14. Taborelli, R. V., I. G. Bowen and E. R. Fletcher, Tertiary effects of blast - Displacement. Operation Plumbbob Report, WT-1469, May 22, 1959.

15. White, C. S., Biological blast effects. pp. 311-372 of Hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, Congress of the United States, Eighty-Sixth Congress, First Session on Biological and Environmental Effects of Nuclear War, Part I, June 22-26, 1959, U. S. Government Printing Office, 1959.

16. Richmond, D. R., R. V. Taborelli, I. G. Bowen, T. L. Chiffelle, F. G. Hirsch, B. B. Longwell, J. G. Riley, C. S. White, F. Sherping, V. C. Goldizen, J. D. Ward, M. B. Wetherbe, V. R. Clare, M. L. Kuhn and R. T. Sanchez, Blast biology - A study of the primary and tertiary effects of blast in open underground protective shelters. Operation Plumbbob Report, WT-1467, June 30, 1959.

17. White, C. S., Biological blast effects. USAEC Report TID-5564, Lovelace Foundation for Medical Education and Research, September 1959.

18. White, C. S. and D. R. Richmond, Blast biology. USAEC Report TID-5764, Lovelace Foundation for Medical Education and Research, September 18, 1959.

19. Richmond, D. R., C. S. White, R. T. Sanchez and F. Sherping, The internal environment of underground structures subjected to nuclear blast. II. Effects on mice located in heavy concrete shelters. Operation Plumbbob Report, WT-1507, May 31, 1960.

20. White, C. S. and D. R. Richmond, Blast biology. Chapter 63, in Clinical Cardiopulmonary Physiology, edited by Ross C. Kory and Burgess L. Gordon, Grune and Stratton, Inc., New York, 1960.

21. White, C. S., I. G. Bowen, D. R. Richmond and R. L. Corsbie, Comparative nuclear effects of biomedical interest. Civil Effects Test Operations, USAEC Report CEX-58-8, January 12, 1961.

22. Goldizen, V. C., D. R. Richmond, T. L. Chiffelle, I. G. Bowen and C. S. White, Missile studies with a biological target. Operation Plumbbob Report, WT-1470, January 23, 1961.

23. Bowen, I. G., R. W. Albright, E. R. Fletcher and C. S. White, A model designed to predictthe motion of objects translated by classical blast waves. Civil Effects Test Operations, USAEC Report CEX-58.9, June 29, 1961.

24. Fletcher, E. R., R. W. Albright, V. C. Goldizen and I. G. Bowen, Determinations of aerodynamic-drag parameters of small irregular objects by means of drop tests. Civil Effects Test Operations, USAEC Report CEX-59.14, October 1961.

25. Richmond, D. R., I. G. Bowen and C. S. White, Tertiary blast effects: Effects of impact on mice, rats, guinea pigs and rabbits. Technical Progress Report on Contract DA-49-146-XZ-055. Also published as DASA 1245, Defense Atomic Support Agency, Washington 25, D. C., February 28, 1961, and in Aerospace Med., 32: 789-805, 1961.

26. Richmond, D. R., V. R. Clare, V. C. Goldizen, D. E. Pratt, R. T. Sanchez and C. S. White, Biological effects of overpressure. II. A shock tube utilized to produce sharp-rising overpressures of 400 milliseconds duration and its employment in biomedical experiments. Technical Progress Report on Contract No. DA-49-146-XZ-055. Also published as DASA 1246, Defense Atomic Support Agency, Washington 25, D. C., April 7, 1961 and in Aerospace Med., 32: 997-1008, 1961.

27. Richmond, D. R., V. C. Goldizen, V. R. Clare, D. E. Pratt, F. Sherping, R. T. Sanchez, C. C. Fischer and C. S. White, Biologic response to overpressure. III. Mortality in small animals exposed in a shock tube to sharp-rising overpressures of 3 to 4 msec duration. Technical Progress Report on Contract DA-49-146-XZ-055. Also published as DASA 1242, Defense Atomic Support Agency, Washington 25, D. C., June 15, 1961 and in Aerospace Med., 33: 1-27, 1962.

28. White, C. S., Biological effects of blast. Presented before The Armed Forces Medical Symposium, Field Command, Defense Atomic Support Agency, Sandia Base, Albuquerque, New Mexico, November 28, 1961. Submitted as a Technical Progress Report on Contract DA-49-146-XZ-055 to the Defense Atomic Support Agency in December 1961. Published as DASA 1271, Defense Atomic Support Agency, Washington 25, D. C., December 1961.

29. Bowen, I. G., M. E. Franklin, E. R. Fletcher and R. W. Albright, Secondary missiles generated by nuclear-produced blast waves. Operation Plumbbob Project 33.2 Report, WT-1468, submitted to Mr. L. J. Deal, Division of Biology and Medicine, U. S. Atomic Energy Commission, on March 7, 1962. (In press)

30. Richmond, D. R., D. E. Pratt and C. S. White, Orbital "blow-out" fractures in dogs produced by air blast. Submitted as a Formal Progress Report on Contract DA-49-146-XZ-055 to the Defense Atomic Support Agency on April 10, 1962. (To be published as DASA 1316)

31. Fletcher, E. R., R. W. Albright, R. F. D. Perret, M. E. Franklin, I. G. Bowen and C. S. White, Nuclear bomb effects computer. Submitted to Mr. L. J. Deal, Division of Biology and Medicine, U. S. Atomic Energy Commission on May 21, 1962. (In press)

32. Clare, V. R., D. R. Richmond, V. C. Goldizen, C. C. Fischer, D. E. Pratt, C. S. Gaylord and C. S. White, The effects of shock tube generated, step-rising overpressures on guinea pigs located in shallow chambers oriented side-on and end-on to the incident shock. Technical Progress Report on Contract DA-49-146-XZ-055 submitted to the Defense Atomic Support Agency on May 31, 1962. (In press)

33. Richmond, D. R, The exposure of guinea pigs to pressure-pulses generated during the end-to-end test (No. 2) of Atlas missile 8-D (March 31, 1962). Technical Progress Report on Contract DA-49-146-XZ-055 submitted to the Defense Atomic Support Agency on July 20, 1962. (In press)

34. Richmond, D. R., V. C. Goldizen, V. R. Clare and C. S. White, The overpressure-duration relationship and lethality in small animals. Technical Progress Report on Contract DA-49-146-XZ-055 submitted to the Defense Atomic Support Agency on September 10, 1962. (In press)

35. Desaga, Hans, Blast injuries. Chap. XIV-D, pp. 1274-1293, German Aviation Medicine, World War II, Vol. II, U. S. Government Printing Office, Washington, 1950.

36. Benzinger, Theodor, Physiological effects of blast in air and water. Chap. XIV-B, pp. 1225-1259, German Aviation Medicine, World War II, Vol. II, U. S. Government Printing Office, Washington, 1950.

37. Rõssle, Robert, Pathology of blast effects. Chap. XIV-C, pp. 1260-1273, German Aviation Medicine, World War II, Vol. II, U. S. Government Printing Office, Washington, 1950.

38. Schardin, H., The physical principles of the effects of a detonation. Chap. XIV-A, pp. 1207-1244, German Aviation Medicine, World War II, Vol. II, U. S. Government Printing Office, Washington, 1950.

39. Coates, Jr., J. B. and J. C. Beyer, Wound ballistics. Office of the Surgeon General, Department of the Army, U. S. Government Printing Office, Washington 25, D. C., 1962.

40. Blocker, V. and T. G. Blocker, The Texas City disaster — A survey of 3,000 casualties. Am. Jour. Surg., LXXVIII: 756-771, 1949.

41. Richmond, D. R., V. R. Clare and Clayton S. White, The tolerance of guinea pigs to air blast when mounted in shallow, deep, and deep-with-offset chambers on a shock tube. Submitted as a Technical Progress Report on Contract No. DA-49-146-XZ-055 to the Defense Atomic Support Agency on October 27, 1962.

42. Richmond, D. R. and C. S. White, A tentative estimation of man's tolerance to overpressures from air blast. Presented before The Symposium on Effectiveness Analysis Techniques for Non-Nuclear Warheads Against Surface Targets, U. S. Naval Weapons Laboratory, Dahlgren, Virginia, October 30, 1962. (To be submitted as Technical Progress Report to DASA)

43. Stewart, G. M., The resistance of rabbit eye to steel spheres and cubes. Technical Report CWLR-2332, U. S. Army Chemical Warfare Laboratories, Army Chemical Center, Md., January 1960.

44. Lissner, H. L. and F. G. Evans, Engineering aspects of fractures. Clin. Orthop., 8: 310-322, 1958.

45. Zuckerman, S. and A. N. Black, The effect of impact on the head and back of monkeys. Report RC-124. Ministry of Home Security, Oxford, England, August 12, 1940.

46. Gurdjian, E. S., J. E. Webster and H. L. Lissner, Biomechanics: Fractures, skull. In Medical Physics, Vol. II. Chicago: The Year Book Publishers, Inc., 1950, pp. 99-105.

47. Swearingen, J. J., E. B. McFadden, J. D. Garner and J. G. Blethrow, Human tolerance to vertical impact. Aerospace Med., 31: 989-998, 1960.

48. DeHaven, Hugh, Mechanical analysis of survival in falls from heights of fifty to one hundred and fifty feet. War Med., 2: 586-596, July 1942.

49. Cohen, E. and A. Bottenhofer, Test of German underground personnel shelters. Operation Plumbbob Report, WT-1454, July 1960.

50. Davis, T. P., N. D. Miller, T. S. Ely, J. A. Basso and H. E. Pearse, The scattering of thermal radiation into open underground shelters. USAEC Report CEX-58.2, May 1959, Office of Technical Services, Department of Commerce, Washington 25, D. C.

51. Greig, A. L. and H. E. Pearse, Thermal radiation measurements (Parts I and II). Operation Plumbbob Report, ITR-1502, January 1958, Office of Technical Services, Department of Commerce, Washington 25, D. C.

52. Vortman, L. J., Evaluation of various types of personnel shelters exposed to an atomic explosion. Operation Teapot Report, WT-1218, May 1956, Office of Technical Services, Department of Commerce, Washington 25, D. C.

53. Williamson, R. A. and P. H. Huff, Test of buried structural-plate pipes subjected to blast loading. Operation Plumbbob Report, WT-1474, August 1960, Office of Technical Services, Department of Commerce, Washington 25, D. C.

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